'Force of Nature' Climate Shocks, Food Crises and Conflict in Colonial Africa and Asia, 1880-1960

Global climate change poses one of the most urgent challenges of our age. The increasing frequency and intensity of weather shocks, such as heat waves, droughts, floods, and hurricanes, are all anticipated to adversely affect conditions of agricultural production, and jeopardize efforts to achieve global food security. In recent years, there has been a rapidly growing body of literature across multiple disciplines aiming to quantify and assess the adverse consequences of climate on relatively poor rural societies. Building entirely on original primary sources, this dissertation provides evidence that weather shocks raised property crime, triggered civil conflict and shaped patterns of human settlement in British colonial Africa and Asia during the first half of the twentieth century (~1880-1960). By merging the theoretical and empirical insights of several strands of literature (e.g. economics, history, geography), this dissertation has both academic and social merit. Its academic merit lies in its promise to disentangle the net effect of climate on societies from the many other contextual factors that may affect them. And its social merit lies in its capacity to reveal key factors that can mitigate the adverse consequences of weather shocks, enabling tailor-made policy interventions. In sum, the present dissertation contributes to a better understanding of long-term agrarian development in tropical Africa and Asia, offering fresh input to academic debates on how to mitigate the effects of weather extremes.

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'Force of Nature'

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2017

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Climate Shocks, Food Crises and Conflict in Colonial Africa and Asia, 1880-1960

Propositions

1. Despite two centuries of technological and agrarian progress since the industrial revolution, it may come as a surprise that the connection between climate and human settlement has remained strong until today.
   (this thesis)

2. Poverty traps, as well as the subsequent vicious cycles of crime and conflict, could be eliminated by the promise of a stable annual harvest.
   (this thesis)

3. As more and more people get their news exclusively from social media, fact-checking appears to be suffering from a slow death.

4. The recent Greek debt crisis demonstrates the pitfalls of relying on external financing, which may significantly undermine state sovereignty.

5. The most effective way to increase your life expectancy is to build a strong network of good friends.

6. A profound awareness of the inevitability of death and the fragility of life could make individuals show more empathy, compassion and solidarity.

Propositions belonging to the thesis entitled: "Force of Nature: Climate Shocks, Food Crises and Conflict in Colonial Africa and Asia, 1880-1960".

Kostadis Papaioannou

Wageningen, 02 June 2017

‘Force of Nature’

Climate Shocks, Food Crises and Conflict in Colonial Africa and Asia, 1880-1960.

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‘Force of Nature’

Climate Shocks, Food Crises and Conflict in Colonial Africa and Asia, 1880-1960.

Kostadis J. Papaioannou

Thesis

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There are many injustices in the world, but
there is one of which no one speaks,
which is that of climate.

–Albert Camus

Contents

CHAPTER 1

Introduction

1.1 Climate & Society: Past & Present

The idea that climate may substantially influence human behavior and economic performance is a very old one and dates back to the writings of Ancient Greeks and Roman historians, enduring in the essays of major figures of the Enlightenment. In *On Airs, Waters, and Places* (400 B.C.E) Hippocrates noted that "places where the changes of the seasons are most frequent, and where they differ most from one another, there you will find the greatest differences in men's physique, disposition, and temperament". Similarly, Tacitus in *Germania* (98 A.D) asserted that climate brings about a similarity of manners among people living in adjoining lands. He noted that "climatic conditions stamp a certain physique on the human body",[1] rendering some of them "accustomed to cold and hunger", and others "unable to bear thirst and heat". Centuries later, Montesquieu in *The Spirit of the Laws* (1748) set forth to understand how geography and climate interact with particular cultures to "produce the spirit of a people", arguing, among other things, that hot climates increase extreme emotionality, immorality and criminality.[2] Besides climate's impact on individual and social behavior, Montesquieu also discussed the adverse economic consequences in productivity levels, highlighting that the "heat of the climate can be so excessive that the body will be absolutely without strength" causing "indolence" and "sluggishness".

Historical processes of agricultural development, trade integration and productivity growth were always, to varying degrees, constrained by geographical conditions. No civilization in the past flourished for long without an effective strategy to cope with climatic variability –i.e. a strategy that would facilitate the

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[1] "caeli corporibus habitum dedit" (*Germania* 98 A.D. p. 189 in G. Anderson's (ed.) 1938)

[2] "You will find in the northern climates peoples who have few vices, enough virtues, and much sincerity and frankness. As you move toward the countries of the south, you will believe you have moved away from morality itself: the liveliest passions will increase crime" (Montesquieu 1748/1989, p.234)".

production and trade of food in sufficient quantity and quality. Food surpluses are needed to collect taxes, raise armies, wage wars and build cities. Nowadays in particular, few would dispute that climate is intrinsically linked to core issues for all societies –including health, food production and energy use among others.

The view that adverse climatological conditions, or 'geography' in the broad sense of the term,[3] have been responsible for disappointing productivity growth in *tropical agriculture* more so than in temperate parts of the world, has been expressed for centuries. Such view features prominently in Adam Smith's *Wealth of Nations* (1776), where he argues that the lack of opportunities for sea-bound trade and related labor specialization have impeded the development of markets and division of labor in the tropics, and especially in Africa,[4] suggesting that in regions located far from coasts and ocean-navigable rivers, transport costs of international trade are high. Great thinkers and prominent historians, such as William McNeill (1963), Alfred Crosby (1986) and Fernand Braudel (1973; 1995), have also seen geography and climate as crucially determining factors in explaining divergent development paths between *temperate* Europe and *tropical* Africa in the *longue durée*; or following their terms, divergent development paths between geographically and climatologically 'advantaged' and 'disadvantaged' regions. These scholars draw on an extensive range of sources to allude Europe's advantages in maritime superiority, temperate climate, agricultural productivity and disease environment as fundamental conditions for its take-off and eventual domination of the Americas. As Braudel (1995, p.120) eloquently puts it: "*in understanding Black Africa, geography is more important than history. The geographical context is not all that matters, but it is the most significant*".

Traditionally, a great deal of previous research hinges on the idea that Africa's major disadvantages in coastal trade, navigable rivers, disease ecology, and

[3] Geography here is used in the broad sense of the term and refers to the relationships between people and their environment including the opportunities and constraints posed by physical conditions along with ecological constraints.
[4] "There are in Africa none of those great inlets, such as the Baltic and Adriatic seas in Europe, [...] to carry maritime commerce into the interior parts of that great continent" (p.25)

soil fertility are mainly responsible for its agricultural and economic stagnation (McNeill, 1963; Crosby, 1986; Sachs & Warner, 1997; Landes, 1998; Curtin, 1998; Diamond, 1999; McNeill, 2010). More recently, a series of empirical studies have investigated the link between climate and agricultural output, suggesting a strong adverse effect of tropical ecozones on the market value of agricultural output (see Bloom et al., 1998; Gallup et al., 1999; Sachs, 2001; Easterly & Levine, 2003; Rodrik et al., 2004). For example, Gallup et al. (1999) show that *tropical agriculture* suffers a productivity decrement of 30 percent to 50 percent compared to temperate-zone agriculture (p. 197), concluding that at "the root of Africa's poverty lies its extraordinarily disadvantageous geography".

Thus far, a number of factors have frequently been invoked to account for Africa's obstacles to growth. A key factor being the (i) chronically low agricultural productivity (especially food production); another one being the (ii) difficulties to store food, as food preservation is more challenging in tropical climates than in temperate ones. Increased humidity and relatively hot winters reduce the possibility to store food for the later months of the year (i.e. long after harvest, known by many as 'hunger months'), thereby limiting opportunities to (iii) transport food and produce to distant markets; (iv) a fourth factor being the light and low in nutrients soils, which under heavy rains are subject to rapid nutrient leaching.

That tropical regions have been, and still are, at a disadvantage in agricultural development has been widely advocated. Nevertheless, wide variations *within the tropics exist*. Human, plant and animal diseases have been thought to be notably worse in *tropical Africa* than in *tropical Asia* or *tropical America* (Diamond, 1999; Gallup et al., 1999; McNeill, 2010; Hsiang & Meng, 2015; Frankema, 2015). For instance, the Tsetse fly is unique to Africa and transmits a parasite harmful to humans and lethal to livestock. Historically, such a disease burden has limited the availability of animal manure and animal draft power, which, as a result, has hindered the ability of Africans to generate agricultural surpluses. Surpluses that constitute a vital element for the growth of historical populations and human settlement, as they stimulate investments in agricultural and transportation technology (Goody, 1980; Alsan, 2014; Frankema, 2014).

Malaria and a number of other tropical infectious diseases have also been more severe in tropical Africa than elsewhere. Malaria's vectors of transmission are greatly influenced by certain climatological conditions akin to tropical climates. For example, high humidity, enduringly high temperatures –interacted with prolonged rainy seasons, attain the mosquito's ideal range more often, encouraging more frequent biting and faster mosquito reproduction. Even today, sub-Saharan Africa continues to bear the brunt of the global burden of malaria, being home to 89% of malaria cases and 91% of malaria deaths (WHO, 2008). Endemic tropical diseases have posed considerable barriers to long term economic growth, since they impede agricultural intensification and the exchange of agricultural commodities, effectively shrinking the prospects for enhanced division of labor and increasing agricultural returns.

From a climatological point of view, Sub-Saharan Africa is generally dryer, experiences droughts more frequently than any other part of the tropical world, and faces more erratic rainfall patterns (Bloom et al., 1998; Le Blanc & Perez, 2007). Under relatively predictable rainfall patterns, farmers adapt their production practices to maximize their yields. However, under high levels of rainfall variability (where more frequent and intense shocks occur), such adaptation becomes more difficult, hampering long-term investments in soil improvements and other technological innovations. And, although there have been two centuries of historical dynamics and agrarian change since the industrial revolution, it may come as a surprise that the connection between climate and human settlement patterns has remained visible up to the present time.

In recent years, there has been renewed interest in the '*climate-society nexus*', which has prompted a wide surge of quantitative analyses seeking to test theories and assess the validity of previously proposed linkages. This surge can be partly explained by rising public concerns about climate change and its potentially distortive effects on societal cohesion; partly by greater popular awareness of the critical role that climate might play in driving economic outcomes; and partly by methodological advances and data availability, combined with improvements in computing power. As a result, there is a growing body of literature across multiple scholarly disciplines –including economics, psychology, epidemiology, geography, and history– that aims to quantify and assess the effects of climate on a number of socially and economically relevant outcomes (e.g. agricultural yields, mortality rates, crime, conflict etc.). This new line of research uses panel methodologies (longitudinal data), enabling researchers to exploit high-frequency (e.g. month-to-month or year-to-year) changes in the climate variables (e.g. rainfall, temperature), while simultaneously controlling for space- and time-unobservable effects across numerous locations (what economists call fixed effects). This dissertation is part of this new research wave.

Its main contribution lies in the fact that it aims to identify the *causal pathways* that drive the climate-economy relationship and that it provides insights from a historical-social context (that of colonialism) that has not yet been subjected to this kind of analysis. To achieve that, it addresses a major methodological problem that lies at the core of the existing economic and economic-historical literature; i.e. endogeneity and reverse causality. The principal advantage of this new panel-data approach is identification (see *Chapter 4*). Identifying the key pathways and impact of climate on societies should be particularly valuable to designing modern policies that best respond to climatic events.

Additionally, this newly emerging literature often examines the *heterogeneous* impact of climate on societies and their economies. Heterogeneity may exist with regard to the climatic variables themselves, as well as with regard to the outcome variables. A good example for the latter is that better institutions or 'deeper' trade integration could decrease the vulnerability to climate shocks, and that certain social groups –such as pastoralists, or export crop farmers– may be less vulnerable to these shocks. Investigating and narrowly identifying the conditions that *mitigate* the impact of these shocks on rural societies, holds great promise as it would help target potential effective interventions. In Chapters 2 and 3, we use such an approach to review a long-standing and heated debate in economic-historical literature: the issue of whether agricultural commercialization was beneficial or detrimental to rural livelihoods. Or, to put it differently, whether the cultivation of export crops operated as a *mitigating* mechanism in increasing farmers' resilience to extreme climatic events. Our findings suggest that the surplus revenues generated by export crops partially alleviated negative rural income shocks. We believe that the more we grow to understand and identify *adaptive* mechanisms, the better responses we can devise.

Another notable contribution of this dissertation is the extensive and functional use of *original archival sources*. Besides enabling us to assemble several new panel datasets for a wide variety of indicators that are *spatially* and *temporally* consistent, and *internationally* comparable, these sources were conducive (a) in formulating theoretical hypotheses by taking the local context into consideration, (b) in obtaining a more thorough understanding of the important mechanisms driving the underlying relationship, and (c) in adding a new layer of robustness by backing up the regression results. Unfortunately, virtually all studies in this field are solely based on econometric correlations, and make no attempt to contextualize their findings. We expect that dual methodological approaches will serve as the base for future studies in both climate-economics and environmental history.

The impact of climate on our societies is a topic of considerable urgency today as the process of global climate change accelerates, generating more severe and unpredictable climate events. While much work remains to be done in developing a road map of adaptation to global warming, carefully understanding the key *causal pathways* and *mitigating factors* would help target potential interventions. Our ambition is that a cautious understanding of the nature, occurrences and consequential impact of climatic events will enable societies to assess the "cost function" of future climate change, and to effectively design their contemporary adaptive institutions and economic policies.

1.2 Scientific & Societal Relevance

Climate change and its potential threatening impacts is one of the major concerns of our age. Warming global temperature, changing precipitation schemes, expansion of deserts and extreme heat waves are all anticipated to result in a rapid decline of habitation, thus increasing public concerns about global food security. Such concerns have boosted a great amount of research that seeks to reliably quantify the effects of extreme climatic variability on economically and societally relevant outcomes (the key trends being: conflict and crime, health and mortality, and agricultural yields and productivity). The literature is also inspired by growing public concerns about the potentially distortive effects of climate change on societal cohesion as it raises awareness of *global interrelatedness* (Johnstone & Mazo, 2011). For example, the exceptionally dry winter in China in 2010–2011 led to global wheat shortages. These shortages had a particularly severe impact on Egypt, the world's largest wheat importer, where, during the period November 2010 to March 2011, bread prices soared to a level that was unaffordable for most low-income households. This is now believed to have planted the seeds that, along with other social, economic and political factors, eventually led to the Arab Spring in Egypt and beyond (Sternberg, 2012).

Rather than accepting a static link between climate and social outcomes, a key challenge is to understand which conditions aggravate or mitigate the impact of climate shocks, and to learn more about the local determinants of resilience and adaptation. Classical economic theory predicts that trade integration stimulates employment opportunities in agricultural activities, allowing farmers to diversify their risk by marketing their surplus produce (Smith, 1776). Thus, a recurring theme in this thesis is whether the agricultural commercialization (adoption and expansion of cash crops) that took place in the early twentieth century could have increased the resilience of local farmers in withstanding extreme climatic events.

Our results are interesting also from a public policy perspective, as they support the idea that smallholder-based export cultivation enables farmers to spread risk, smooth their consumption patterns, and profit from inter-regional and international trade (*Chapters 2 & 3*).

Scholars inevitably acknowledge that climatic hazards were, and still are, generally more severe in Africa and Asia, if taken on a global comparative perspective. Such climate-induced dangers include rapid decline of habitation, food shortages and near-famine conditions. Africa and Asia's rising population densities and resurging socio-political instability contribute to making this a most pressing concern. As global temperatures are likely to rise substantially over the next decades, and more frequent and intense climatic phenomena are expected, exposing and identifying these conditions may be essential to allow societies to better deal with potential future disastrous shocks and calamities.

More recently, a few scholars have begun to recognize that the direct effects of climate change will differ from region to region around the world and will disproportionally impact on the poor farmers of the global south. In a predominantly agrarian society, economic prosperity is intimately tied to agricultural output, and thus, in the wake of extreme annual climatic events, loss of a year's harvest can easily push poor farmers into extreme poverty. Our findings corroborate this line of evidence, since we find that the poorest segments of society were hit the hardest (*Chapter 4*).

Beyond improving our understanding on local conditions of early twentieth century Africa and Asia, the implication of this study may be important from a public policy perspective in contemporary developing countries. Taken together, the results of this dissertation support the idea of improved high-yield weather-resistant grains and investments in irrigation technology. The promise of a stable annual harvest would potentially eliminate much of the adverse climate-induced poverty traps, as well as the subsequent unfolding vicious cycles of crime and conflict. Unfortunately, climate change continues and it is going to bring about more erratic climatic events, hitting the poorest smallholder farmers the most. A key policy priority should therefore be to aim at a long-term protection of the most vulnerable and precarious farmers of the global south.

1.3 Research Objectives & Key Innovations

This dissertation aims to make several noteworthy contributions by linking an *academic challenge* (i.e. *unravel* the *net* effect of climate on socio-economic outcomes from many other potentially influential factors) to a *social question* of prime importance (i.e. *reveal* key factors that mitigate such adverse effects). Its overarching objectives are (a) to quantify and assess the impact of climate on a variety of agrarian societies in tropical Africa and Asia, (b) to identify the key *causal pathways* from climate to society, and (c) to reveal key *mitigating factors* that would enable these societies to target their policy interventions and design adaptive institutions.

Here, we provide a summary of its innovative aspects. *First*, we quantify and assess the effect of short-term climatic variability on several societally and economically relevant outcomes (such as conflict, crime and agricultural yields), and we *causally* identify the loss of (agricultural) income as being the most relevant mechanism that drives the relationship.

Its *second* innovative aspect lies in its interdisciplinary methodological approach, as it combines *social science methods* (econometric analysis) and historical narrative, to expose the paramount significance of agricultural commercialization in *alleviating* distress of rural livelihoods in the wake of climate shocks. By merging the theoretical and empirical insights of those two strands of literature, we provide strong evidence supporting the idea that the surplus revenues generated by export crops partially mitigated the negative rural income shocks.

Third, we refine existing variables of measuring climate shocks. Instead of focusing on droughts only, throughout the dissertation we argue that both *droughts* and *excessive rainfall* (floods) are equally important in explaining the outcomes of interest. We conceptualize and econometrically parameterize the principal (climate-to-society) relationship as being non-linear (U-shaped). Such conceptualizations are also in line with the insights we gained while analyzing the archival sources. Although we find a robust and significant curvilinear effect of climatic variability on various outcomes, it should be noted that the effect was never fully symmetrical and was highly dependent on the context applied (e.g. Africa as opposed to Asia). We believe that the empirical methods used for these regions may be applied to other regions elsewhere in the world.

Fourth, this dissertation yields several new panel datasets for a wide variety of indicators which are *spatially* and *temporally* consistent, and *internationally* comparable. While the *climate-economy* literature has been steadily rising over the past few years, no single study exists for tropical Africa and Asia prior to 1960. One of the key objectives of this dissertation is to contribute to a *considerable expansion of the time horizon* to an era before notable global anthropogenic carbon emissions. The systematic data collection from primary historical archives enables us to obtain information on indicators of climate (rainfall, temperature, solar radiation etc.), conflict and crime (theft, assaults, cattle-raiding, prisoners etc.), as well as agriculture (rice, wheat etc.), which should prove particularly valuable to the construction of original and freely-available data-series for the pre-1960 period.

To date, we possess hardly any evidence on *observed* (i.e. from meteorological stations) monthly and annual climate data prior to 1960. To overcome such data gaps, researchers have developed a number of *forecasted* weather datasets, using either interpolations across space and time or data assimilation algorithms. While these procedures offer free and easily imported climate datasets in formats that can be used by many researchers (e.g. gridded data), they also increase the statistical uncertainty of resulting parameter estimates (Hsiang, 2016). And whereas these gridded climate datasets have a high compatibility when the *average* value of weather variables is taken – i.e. areas that are on average cold or hot in a given year-, the derived *deviations* around the mean can be significantly different (Dell et al., 2014; Hsiang, 2016). Such differences appear even stronger in tropical settings and in precipitation returns (Auffhammer et al., 2013). The latter is due to the fact that rainfall is less smooth than temperature in space and time, which as a result, increases uncertainty when extrapolated (see Auffhammer et al., 2013, pp. 5-8). Additionally, there are drawbacks from an econometric point of view. These data-generating processes often display significant spatial correlation and increased risk of measurement error. Such statistical concerns may lead to inflated standard errors and biased estimated coefficients (Wooldridge, 2010; Auffhammer et al., 2013). Thus, the ground meteorological stations should be preferred and our ambition is that the newly constructed climatological series could be connected to the existing post-colonial climate series, filling this gap of knowledge.

Fifth, this is the first time that historical data from meteorological stations have been used to explore whether the differences in climatic variability between tropical Africa and tropical Asia have been of a structural nature and independent of high anthropogenic carbon emissions. Research exploring whether African farmers in the tropics face higher levels of climatological insecurity than elsewhere has mainly made use of contemporary data (Gallup et al., 1999; Otsuka & Larson, 2014). The use of such data has been criticized for being substantially affected by global warming (Hsiang et al., 2013). Thus, by looking at the 1910-1940 period; that is, before the first effects of carbon emissions on climate systems were noted, we are better able to assess differences in climatic patterns.

Additionally, we associate these climatic differences to agricultural intensification, as proxied by population density, to add supporting evidence to the idea that climatological instability breeds higher cultivation risks and worse prospects for investments in agricultural technologies. The current findings complement those of earlier studies and should prove to be particularly valuable to the growing discussion on the origins of the Green Revolution, and whether Africa will complete a green revolution of its own.

Last but not least, throughout this dissertation, we make extensive and functional use of primary archival material (a) to formulate theoretical hypotheses by taking the local context into consideration, (b) to obtain a more thorough understanding of the important mechanisms driving the relationship of interest, and (c) to add a new layer of robustness by backing up the regression results. Regrettably, while extensive research has been carried out on the climate-society nexus, no single study exists that offers anecdotal evidence.

1.4 Setting of this study

1.4.1 Temporal & Spatial Demarcation

The final decades of colonial rule form an interesting period for a study of the African and Asian colonies for several reasons (Figure 1). *First*, the time frame guarantees a rather uniform and stable institutional framework under British colonial rule, as the onset of the 20th century marked the end of effective resistance to British rule and the establishment of persistent colonial borders, while the 1950s and early-1960s marked the beginning of serious internal resistance to colonial policies and many independence movements gained real power at the political arena —like, for instance, the Mau Mau uprising in Kenya. *Second*, Britain administered a vast empire in the tropics, where the state's key preoccupations were related to law and order, public infrastructure (railways, schooling, hospitals etc.) as well as agricultural commercialization, leaving behind an extensive bureaucratic legacy. A legacy that provides a unique opportunity for a two-pronged research strategy, involving both *qualitative* and *econometric* methods.

Third, within their borders the selected countries contain a wide range of geographical (such as agro-ecological zones) and institutional (such as pre-colonial political entities) features, which allow us to derive meaningful comparisons, both between countries and between continents. *Fourth*, this setting enables us to review a long-standing and unsettled debate in economic-historical literature on the impact of agricultural commercialization on rural livelihoods. The literature largely agrees that tropical economies have expanded, to varying degrees, in response to increasing colonial trade and agricultural commercialization, but the extent to which ordinary farmers benefitted from such developments remains unclear. Such unresolved concerns remain pervasive in recent debates on agricultural intensification and commercialization in Sub-Saharan Africa and particularly the impact of 'Green Revolution' technologies and policy interventions on food security and rural incomes (Collier & Dercon, 2014; Dawson et al., 2016). *Fifth*, by focusing on an era prior to notable anthropogenic carbon releases and when rapid demographic booms and processes of urbanization across the developing world were not yet present, we were able to explore whether African farmers in the tropics faced higher levels of climatological insecurity.

Figure 1. *African and Asian countries included in our sample, c.1920*

Source: Created by the authors in ArcGIS.

1.4.2 Unit of Analysis

The British colonizers set up an extensive system of administration in their African and Asian dependencies. Territories were divided in provinces, and provinces in districts. At the district level, elaborate administrative accounts were kept. Local (district) officers reported biannually, quarterly or even monthly to their superiors on a wide range of issues –including meteorology, agriculture, native affairs, health, police and prisons. The consistency and regularity with which these reports were kept across colonies, enabled us to create a variety of numerous *temporally* and *spatially* comparable *district-level* panel datasets. [5] To the best of our knowledge, these datasets provide the oldest climate-economy record assembled by researchers in a historical setting (districts $n = 221$ and years $t = 35$).

1.4.3 Data Sources

The sources used are the annual reports filed by the colonial administration, divided into two distinct categories; the *Colonial Office Annual Reports* and the *Blue Books of Statistics*. Their purpose was to provide an in-depth overview of local conditions and affairs during a calendar year. The reports are consistent in their coverage of issues over time and across colonies, and give us a uniquely comprehensive insight into local conditions. All variables used throughout this dissertation are original and directly obtained from the National Archives in London (TNA). Our examination of the colonial administrative record enables us to formulate a range of hypotheses and to expose several key mechanisms which we then test econometrically.

1.4.4 A critical note on sources

A serious weakness is that these reports present information from only one side of the story. Therefore, we need to be careful not to follow the leads from colonial reports without hesitation. The accounts are also imbued with colonial prejudice, paternalistic and derogatory overtones. On top of that, previous scholars have pointed at the incentive to focus on 'progress' and paint a rosy picture to superiors which might have affected the reliability of local administrative accounts. For instance, the cultivation of export crops was considered as one of the key markers of 'progress', so it might in some instances have been in the interest of civil servants to downplay negative aspects of its cultivation and to paint an overly favorable picture of its beneficial effects on local communities. As a result, coverage of events may be incomplete and the representation of certain occurrences biased and flawed. These caveats must be borne in mind.

[5] We allowed for one major exception to this rule, by including data from the Netherlands Indies which exhibit a comparable degree of detail and accuracy.

Nevertheless, there is no reason to believe that references to episodes of famine or unrest were made up. Neither is there reason to believe that relative value free figures (such as rainfall, food prices or prisoners) or controllable figures (cash crop exports) were deliberately and consistently flawed, although incidental mistakes cannot be ruled out. There is also no reason to treat factual information – a bad harvest or the occurrence of a flood– with great suspicion. The local administrator's representation and interpretation of such incidences, however, deserves critical scrutiny and contextualization. Overall, we must bear in mind that British colonial services were often understaffed and local administrators had to improvise and operate on a shoestring and were hardly capable to administer the vast territories they were supposed to control.

1.5 Theoretical Underpinning

Theoretical propositions are the backbone of social science. Empirical research on climatic variability and socio-economic outcomes is frequently criticized for being theoretically underdeveloped (see Seter (2016) for an overview). In thinking about the plausible mechanisms underpinning the climate-economy nexus, it is important to consider some of the proposed theoretical arguments. By highlighting these mechanisms researchers can better understand and identify the key elements in the causal argument and proceed by empirically testing them. Solely adding new datasets to empirical testing does not necessarily improve our understanding of the climate-society linkage. Instead, each tested hypothesis should be anchored in theoretical expectations.

The theoretical mechanisms can be roughly grouped into two main thematic categories of argument: *resource scarcity* and *economic hardship*. The first strand of literature holds that climate-induced *scarcity* of vital resources, such as food and fresh water, intensifies the competition over access to water and land, and increases the possibility of conflict (Homer-Dixon, 1999; Miguel et al., 2004; Grossman & Mendoza, 2003; Kahl, 2006; Buhaug & Rod, 2006). This strand investigates how extreme climate conditions disturb people's livelihoods, creating conditions that are more prone to increase social tension and distress. Such conditions include general population movements (migration), pastoralist mobility and intensified competition over scarce resources, such as wells and pasture land.

While in times of drought, farmers and pastoralists may compete over access to fresh water, often resulting in conflict, rainfall shortages can also have a direct effect on the number of farm animals, as a result of starvation or dying of thirst (Fafchamps et al., 1998). Besides being a source of meat and milk, livestock is also indispensable for crop cultivation (for instance, ploughing and harrowing). A sharp decline in farm animals can thus have a detrimental effect on non-animal food supplies as well.

Even though rainfall surplus can be beneficial to farmers, extreme levels of rainfall are unwanted. Excessive precipitation and subsequent flooding has the potential to seriously damage, or even completely destroy the harvest. Harvest failures have been repeatedly associated with spectacular food price spikes. Moreover, heavy rainfall increases the likelihood of outbreaks of plant diseases, the spread of parasitic organisms and the arrival of locusts; especially when rainfall has been preceded by a drought spell.

The second strand of the literature argues that the impact of climate shocks on *economic hardship* can be framed in terms of an opportunity cost model. In simple economic theory of crime, originally introduced by Becker (1974), individuals are more likely to become involved in criminal activity when they experience a negative income shock, as the stolen property might be regarded as a buffer in alleviating distress. In other words, as agricultural productivity declines, engaging in conflict or crime becomes more opportune relative to participating in 'peaceful' economic activities (the opportunity cost of crime is reduced and thereby increases its incidence). The theoretical underpinnings of this hypothesis have been modelled explicitly by Grossman (1991) and Grossman and Mendoza (2003), using a rational choice paradigm. In these two articles the authors show that the anticipated future resource abundance increases the incremental value attached to survival and, consequently, amplifies the current allocation of time and effort to appropriative conflict (something they name the 'paradox of anticipated abundance').

1.6 Methodological Underpinning of the Research Design

One of the greatest methodological challenges scholars had to address in the past was how to accurately estimate the impact of climatic factors on socio-economic outcomes, given the fact that spatial variation in climate is largely fixed. For example, Russia has always been colder on average than Ghana. While there is a clear cross-sectional correlation between a country's climate and its economic performance, there may be unobservable features that vary across these two countries, which are possibly correlated with temperature (what economists call omitted variable bias).

One approach designed to constrain the influence of omitted variables bias is to enter as many variables in the empirical analysis as possible. However, to date, no clear guidance nor a statistical test exists which could determine that all key determinants have been included in the equation, leaving this approach open to criticism (Hsiang, 2016). For instance, many scholars have recently refuted previously published findings of papers employing a cross-sectional design by simply introducing previously unobserved variables in the equation (Burke et al., 2015; Hsiang, 2016). Thus, drawing causal inferences on the relationship between climate and outcomes of interest using cross-sectional designs, could be very misleading.

Only in the past few years scholars have adopted a new approach that deals with such shortcomings and which yields more reliable estimates. This new approach uses *longitudinal data*, exploiting high-frequency changes in climate variables, while controlling for space and time unobservable effects (what economists call fixed effects). Additionally, the focus has now shifted from investigating the effects of long-term climate *averages* to those of short-term climate *anomalies*. This manuscript's research design is part of this new wave.

1.6.1 Rainfall as the key climate variable

The societal impact of climatic variability seems particularly pronounced in developing agrarian societies. This is not surprising, as a large share of the population depends on rain-fed subsistence agriculture and only a small share of all cultivated land is irrigated (FAO, 2015). Extreme rainfall fluctuations in the form of either drought or floods can easily destroy harvests, jeopardize food security and increase resource competition over cropland and pastures. Consequently, rainfall should be perceived as a key climate variable in terms of its impact both on agricultural productivity and, as a consequence, on rural livelihoods. In this context, thus, the most preferred indicator for measuring climatic variability and climate shocks is sharp rainfall anomalies.

1.7 Thesis Composition & Key Contributions

The chapters are organized as follows. *Chapter 2* offers a historical micro-level analysis of the impact of climate shocks on the incidence of conflict in colonial Nigeria (1912-1945). To measure climate shocks we use the standardized deviation from long-term rainfall patterns, capturing both drought and excessive rainfall. Annual information of court cases, prisoners and homicides are used to capture conflict. Besides a robust and significant curvilinear (U-shaped) relationship between rainfall deviation and conflict intensity, we find that the relationship is weaker in areas that specialize in the production of export crops (such as cocoa, groundnuts and palm oil) compared to subsistence farming areas. This result suggests that agricultural diversification acted as an insurance mechanism against the whims of nature. Additional historical information on food shortages, crop-price spikes and outbreaks of violence is used to explore the climate-conflict connection in greater detail.

In *Chapter 3*, we gradually zoom out from the geographical scope (from a case-study of colonial Nigeria to all British African colonies) to review a long-standing and unresolved debate in African economic history; namely whether the adoption of export crops by smallholders was beneficial or detrimental to their ability to cope with climate shocks. To that end, we compile a strongly balanced panel dataset of 151 districts across West, South Central and East Africa in the Interwar Era (1920-1940), and find that the cultivation of export crops had a mitigating effect and made rural communities more resilient to climate shocks. In this chapter, our primary interest is to *causally* identify the effect of cash crops on social distress. The main challenge arises from the fact that cash crop production had to be exogenously determined and not conditionally on other local characteristics. Our findings were robust to using the crop suitability index obtained from FAO (2015) Global Agro-ecological Zones (GAEZ), as well as to using our own newly constructed cash crop per capita indicator. Such findings increase our confidence that the greater resilience to climate shocks observed in the cash crop regions is, in fact, caused by the adoption of cash crops.

Chapter 4 is concerned with the impact of poverty on crime across the rice-economies of South and South East Asia (1910-1940). We use rainfall variation as an instrumental variable for paddy-rice production to estimate the impact of poverty on different types of crime. In line with a growing body of literature on the climate-economy nexus, we offer evidence that loss of agricultural income is one of the main *causal* channels leading to property crime. Previous studies have been unable to resolve the key econometric identification issues and have been potentially subject to bias due to reverse causality and omitted variables, both of which distort simple ordinary least squares (OLS) estimates either downward or upward. In our findings we show that simple OLS estimates are, indeed, biased downward and underestimate the impact of poverty on crime to a substantial degree. The main innovation of this study lies in using rainfall shocks as an exogenous source of variation in food production to identify the relationship between poverty and crime. Although this article's aim is to apply this approach in economic history, it may also be extended to present-day developing countries.

In *Chapter 5*, we assess the long-standing idea that certain climatological conditions in tropical Africa were, on the whole, less conducive to agricultural productivity growth than in tropical Asia. We conduct a multivariate regression analysis to venture more deeply into the various aspects of rainfall variability, and especially the *frequency* and *intensity* of shocks. We find that in an era preceding notable global anthropogenic carbon emissions and the demographic explosion of the second half of the 20th century (i.e. 1910-1940), African farmers were confronted with greater climatological instability than their Asian counterparts. Rainfall shocks in tropical Africa were both more frequent and more severe. Controlling for mean rainfall levels, these shocks explain part of the variation in population density and thus support the idea that climatological instability has created adverse conditions for agricultural intensification. *Chapter 6* reviews the main lessons learned from each chapter, discusses the policy implications and proposes various venues for future research.

References

Alsan, M. (2014). The effect of the tsetse fly on African development. *The American Economic Review*, 105(1), 382-410.

Auffhammer, M., Hsiang, S. M., Schlenker, W., & Sobel, A. (2013). Using weather data and climate model output in economic analyses of climate change. *Review of Environmental Economics and Policy*, 7(2), 181-198.

Bates, R. H. (1981). *Markets and States in Tropical Africa: The Political Basis of Agricultural Policies*: University of California Press.

Bloom, D. E., Sachs, J. D., Collier, P., & Udry, C. (1998). Geography, demography, and economic growth in Africa. *Brookings papers on economic activity*, 1998(2), 207-295.

Braudel, F. (1973). *Capitalism and material life, 1400-1800* (Vol. 1). HarperCollins.

Braudel, F. (1995). *The Mediterranean and the Mediterranean world in the age of Philip II*. University of California Press.

Becker, G. S. (1974). Crime and punishment: An economic approach. In *Essays in the Economics of Crime and Punishment* : 1-54.

Buhaug, H., & Rød, J. K. (2006). Local determinants of African civil wars, 1970–2001. *Political Geography*, 25(3), 315-335.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Climate and conflict (No. w20598). National Bureau of Economic Research.

Collier, P., & Dercon, S. (2014). African Agriculture in 50Years: Smallholders in a Rapidly Changing World?. *World development*, *63*, 92-101.

Crosby, A. W. (1986). *Ecological imperialism: The biological expansion of Europe, 900-1900*. Cambridge, UK: Cambridge University Press.

Curtin, P. D. (1998). *Disease and empire: The health of European Troops in the Conquest of Africa*. Cambridge University Press.

Dawson, N., Martin, A., & Sikor, T. (2016). Green revolution in Sub-Saharan Africa: Implications of imposed innovation for the Wellbeing of rural smallholders. *World Development*, *78*, 204-218.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature*, 52(3), 740-798.

Diamond, J. (1999). *Guns, germs, and steel: The fates of human societies*. WW Norton & Company.

Easterly, W., & Levine, R. (2003). Tropics, germs, and crops: how endowments influence economic development. *Journal of monetary economics*, *50*(1), 3-39.

Fafchamps, M., Udry, C., & Czukas, K. (1998). 'Drought and saving in West Africa: are livestock a buffer stock?'. *Journal of Development economics*, 55(2): 273-305.

FAO (2015). WFP. 2015. *The state of food insecurity in the world.*

Frankema, E. (2014). Africa and the Green Revolution A Global Historical Perspective. *NJAS-Wageningen Journal of Life Sciences*, 70, 17-24.

Frankema, E. (2015). The biogeographic roots of world inequality: Animals, disease, and human settlement patterns in Africa and the Americas before 1492. *World Development*, 70, 274-285.

Gallup, J. L., Sachs, J. D., & Mellinger, A. D. (1999). Geography and economic development. *International regional science review*, 22(2), 179-232.

Grossman, H. I. (1991). A general equilibrium model of insurrections. The *American Economic Review*, 912-921.

Grossman, H. I., & Mendoza, J. (2003). Scarcity and appropriative competition. *European Journal of Political Economy*, *19*(4), 747-758.

Goody, J. (1980). *Technology, tradition and the state in Africa*. CUP Archive.

Hippocrates (400 B.C.E.). *On Airs, Waters and Places* in F. Adams's (Ed.) *The Genuine Works of Hippocrates: Translated from the Greek, with a Preliminary Discourse and Annotations*. William Wood, 1929.

Homer-Dixon, T. F. (1999). *Environment, scarcity, and conflict*: Princeton, NJ: Princeton University Press.

Hsiang, S. M., Burke, M., & Miguel, E. (2013). 'Quantifying the influence of climate on human conflict'. *Science*, 341(6151): 53-67.

Hsiang, S. M., & Meng, K. C. (2015). Tropical economics. *The American Economic Review*, 105(5), 257-261.

Hsiang, S. M. (2016). Climate Econometrics (No. w22181). National Bureau of Economic Research.

Johnstone, S., & Mazo, J. (2011). Global warming and the Arab Spring. *Survival*, 53(2): 11-17.

Kahl, C. H. (2006). *States, scarcity, and civil strife in the developing world*: Princeton University Press.

Le Blanc, D., & Perez, R. (2008). The relationship between rainfall and human density and its implications for future water stress in Sub-Saharan Africa. *Ecological Economics*, *66*(2), 319-336.

Landes, D. S. (1998). *The wealth and poverty of nations: Why some are so rich and some so poor*. New York: Norton.

Mehlum, H., Miguel, E., & Torvik, R. (2006). Poverty and crime in 19th century Germany. *Journal of Urban Economics*, *59*(3), 370-388.

Miguel, E., Satyanath, S., & Sergenti, E. (2004). 'Economic shocks and civil conflict: An instrumental variables approach'. *Journal of political Economy*, 112(4): 725-753.

McNeill, W. H. (1963). *The rise of the West: A history of the human community*. Chicago: University of Chicago Press.

McNeill, J. R. (2010). *Mosquito empires: ecology and war in the Greater Caribbean, 1620-1914*. Cambridge University Press.

Montesquieu, C. S. (1748). *The Spirit of the Laws*. (available in English from Cambridge University Press, Cambridge, UK, 1989).

Otsuka, K., & Larson, D. F. (2014). *An African green revolution*. Springer.

Rodrik, D., Subramanian, A., & Trebbi, F. (2004). Institutions rule: the primacy of institutions over geography and integration in economic development.*Journal of economic growth*, *9*(2), 131-165.

Sachs, J. D., & Warner, A. M. (1997). Fundamental sources of long-run growth. *The American economic review*, 87(2), 184-188.

Sachs, J. D. (2001). *Tropical underdevelopment* (No. w8119). National Bureau of Economic Research.

Seter, H. (2016). Connecting climate variability and conflict: Implications for empirical testing. *Political Geography*, 53, 1-9.

Smith, A. (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations*

Sternberg, T. (2012). Chinese drought, bread and the Arab Spring. *Applied Geography*, 34: 519-524.

Tacitus, P. C. (98). *De origine et situ Germanorum* (Germania) in J.G. Anderson's (Ed.) *Germania*. Oxford: Clarendon Press, 1938.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.

World Health Organization. (2008). *World malaria report 2008*. World Health Organization.

CHAPTER 2

Climate Shocks & Conflict:

Evidence from colonial Nigeria

Abstract

This chapter offers a historical micro-level analysis of the impact of climate shocks on the incidence of civil conflict in colonial Nigeria (1912–1945). Primary historical sources on court cases, prisoners and homicides are used to capture conflict. To measure climate shocks we use the deviation from long-term rainfall patterns, capturing both drought and excessive rainfall. We find a robust and significant curvilinear (U-shaped) relationship between rainfall deviations and conflict intensity, which tends to be stronger in agro-ecological zones that are least resilient to climatic variability (such as Guinean Savannah) and where (pre-)colonial political structures were less centralized. We find evidence that the relationship is weaker in areas that specialize in the production of export crops (such as cocoa and palm oil) compared to subsistence farming areas, suggesting that agricultural diversification acts as an insurance mechanism against the whims of nature. Additional historical information on food shortages, crop-price spikes and outbreaks of violence is used to explore the climate–conflict connection in greater detail.

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2.1 Introduction

"*With few stocks in hand, one year's shortfall could easily be translated into a famine*"

–Megan Vaughan (1987, p. 5)

There is a growing body of literature across multiple scholarly disciplines, including economics, political science and geography, that aims to better understand the impact of climate change on human and social behaviour. This literature is inspired by growing public concerns about the potentially distortive effects of climate change on societal cohesion. The potential impact of climate-induced resource scarcities is even larger in sub-Saharan Africa. As many as 95 percent of the crops cultivated today are rain-fed, while less than 5 percent of all cultivated land is suitable for irrigation (Calzadilla et al., 2013). Consequently, extreme rainfall anomalies in the form of either drought or floods can easily destroy harvests, jeopardize food security and increase resource competition over cropland and pastures.

In this chapter, a case study approach was adopted to gain a detailed understanding of the impact of climate shock on conflict. The contribution of this chapter to existing empirical analyses is fivefold. First, it measures climate shocks through deviations from long-term rainfall patterns in a nonlinear (U-shaped) relation, capturing both drought and excessive rainfall, instead of focusing on droughts only. Second, it introduces a new set of conflict variables. The standard conflict measure usually takes the form of a dummy variable (0,1) on the basis of an arbitrary threshold of 25 deaths in order to fit econometric specifications (Buhaug, 2010; Hendrix & Salehyan, 2012; Raleigh et al., 2010). However, such dichotomous variables neglect a great deal of additional information on the severity of conflict, since the incidence of one more than 25 battle deaths is set equal to, for instance, 125 battle deaths. In this chapter, we adopt four different continuous dependent variables to capture varying magnitudes of conflict. Third, the literature is dominated by large cross-country regressions that use rather short time frames; these fail to shed light on more localized effects of climatic variability in the long-run. Such research designs are mainly invoked by data availability problems. Although the present historical study is also constrained by data limitations, using colonial Nigeria as the case allows us to conduct a panel analysis on a sub-national level for a period of over 30 years (1912–1945). Fourth, almost all studies in this field are solely based on econometric correlations, and make no attempt to contextualize their findings using qualitative evidence. In this chapter, we use primary historical sources (newspapers, government reports) to track food shortages, crop-price spikes and outbreaks of violence, in order to back up the findings of the regression analysis.

Last but not least, with this study we aim to expand existing research agendas to historical periods by merging the theoretical and empirical insights of two strands of literature: the *environmental security* literature, which seeks to investigate whether climate-induced scarcities lead to conflict; and the *economic historical* literature, which assesses the welfare effects of different colonial institutional arrangements and modes of economic specialization (such as the cashcrop revolution). The *environmental security* literature has not reached consensus on the linkage between climate and conflict. Hsiang et al. (2013) claim that climate change may be partly responsible for occasional outbreaks of violence and, more generally, greater economic and political instability. Previous studies have blamed climatic variability for increasing the likelihood of civil wars, or even for directly causing them (Burke et al., 2009; Miguel et al., 2004). These findings have been criticized by other researchers who have pointed to weaknesses in the construction of the climatological variables (Ciccone, 2011), and the level of aggregation of the conflict variables used (Fjelde & von Uexkull, 2012). In line with Fjelde and von Uexkull (2012), we will not argue that climate shocks lead to widespread civil conflict, but rather that the enhanced competition over scarce resources leads to disputes and clashes on a smaller communal scale.

The term "conflict" will be used in its broadest definition in order to encompass a wide range of violent incidents. We observe two distinct categories of communal conflict: (a) civil unrest, such as theft, raiding of livestock, assaults, land disputes between individual resource users, homicides and general armed violence, and (b) small scale communal violence between identifiable social/ethnic groups, such as violent and non-violent actions to evict certain resource users, land disputes between cattle-herders and farmers and largescale destruction of villages. In spite of their calamitous impact on civilian life and property, non-state inter and intercommunal conflicts have received limited attention in the literature.

The *economic historical literature* largely agrees that African economies have expanded, to varying degrees, in response to increasing colonial trade and agricultural commercialization. Yet, the extent to which ordinary Africans have benefitted from such developments remains unclear (Hopkins, 1973; Rodney, 1978). This debate has led to two rather opposing views. The "neo-Marxists" or "dependency theorists" hold that the introduction of new cash crops (such as cocoa) or the expansion of existing cash crops (including palm oil, rubber, coffee and cotton) in Africa has destroyed farmers' traditional insurance mechanisms by inhibiting food production, without replacing them with any new form of security (Vaughan, 1987;Watts, 1983). The alternative view maintains that crop commercialization has provided the means to increase farmers' incomes through the increased benefits reaped from international and inter-regional trade. This diversified farmers' production and therefore limited the vulnerability of cash-crop farmers to the vagaries of climate (Berry, 1975; Fafchamps, 1992). In this chapter, we use closely documented historical sources to answer the underlying question stemming from the aforementioned debate: "Were the cashcrop provinces more – or less– susceptible to climate-induced conflict? Did the introduction of cash crops benefit the local societies, or did it make them more vulnerable to erratic weather fluctuations?"

Colonial Nigeria offers an interesting case for several reasons. As West Africa's largest and most populous nation, it contains within its borders a wide range of geographical (such as agro-ecological zones) and institutional (such as political entities) features; consequently, meaningful comparisons can be derived. Additionally, the time frame of this study guarantees a rather uniform institutional framework under British colonial rule; 1912 marked the end of effective resistance to British rule and the establishment of the borders of the Nigerian colonial state, while 1945 saw the start of serious internal resistance to colonial policies before the independence movement gained any real power.

The sources used are the annual reports filed by the colonial administration. These reports were filed by political departments, and give information and explanations on all incidences of resistance and conflict considered worthy of mention, along with their likely causes. This information will be supplemented and supported by the reports of the police, prison and military departments. Moreover, these reports provide substantial information on both the background and returns of climate-related data, which allowed us to create balanced panel data ($n = 20$, $t = 35$) of all the administrative provinces in colonial Nigeria.

Overall, the results suggest a strong relationship between rainfall deviations and conflict intensity, which tends to be stronger in agro-ecological zones that are least resilient to climatic variability (such as Guinean savannah) and where (pre-) colonial political structures were less centralized. We also find evidence that the relationship is weaker in areas that specialize in the production of export crops. This is a topic of considerable urgency today as the process of global climate change accelerates, generating more severe and unpredictable weather events, as well as more erratic rainfall patterns.

The chapter proceeds as follows. First, it reviews the theoretical and empirical environmental security literature, and discusses the Nigerian colonial context in terms of geographical characteristics, political structures and economic activity. Next, it describes the baseline model, the data and the estimation methodology. Then, it reports the empirical results of the various measures. Finally, it provides detailed evidence from a number of historical cases in colonial Nigeria, and identifies the mechanisms through which climate-induced scarcities led to conflict. A discussion on future research directions concludes the chapter.

2.2 Theory

The primary theoretical relationship between climate shocks and conflict runs via the increased *scarcity* of vital resources such as food and fresh water. A harvest failure leading to food shortages or unexpected declines in freshwater supplies intensifies the competition over access to water and land, and increases the possibility of conflict (Homer-Dixon, 1999). The principal criticism of this simple theoretical argument is that it neglects socio-political and economic contextual factors that play a role in mediating or aggravating the effects of climate-induced scarcities (Bachler et al., 1996; Gleditsch, 1998). This criticism has led to the development of more specific, context-dependent, theoretical mechanisms to explain the causal pathways between climate, demography, environment and conflict (Kahl, 2006).

Even though a large volume of recently published studies aims to link climate-induced scarcities to different incidents of conflict, there is no consensus yet on precisely how these mechanisms operate (Buhaug, 2010). The problem is that most of the research so far has focused on large-scale conflict, such as civil wars (Burke et al., 2009; Miguel et al., 2004). The use of civil war as the dependent variable has been severely criticized on both methodological grounds (Ciccone, 2011) and those of the proposed causal mechanisms (Buhaug, 2010; Gleditsch, 1998). Kahl (2006) and Homer-Dixon (1999) have pointed out that demographic and environmental pressures are more prone to cause inter-communal mini-scale conflict than to cause widespread civil conflict. Recent research has been gradually moving away from larger cross-national conflict studies to use more disaggregated sub-national measures of conflict (Blakeslee & Fishman, 2013; Raleigh & Kniveton, 2012; Theisen, 2012; Voors et al., 2016). In addition, these studies pay more attention to qualitative evidence in order to contextualize their empirical findings, and provide a more subtle argument about the role of climate shocks in outbreaks of communal conflict. The present study can be seen as a contribution to these tendencies.

The last decade has seen interest in the relationship between rainfall variability and conflict (Devlin & Hendrix, 2014; Hendrix & Salehyan, 2012; Miguel et al., 2004). Even though this relationship has become a prominent research issue, it still remains ill-understood and has been highly contested (Klomp & Bulte, 2013), occasionally suggesting contradictive findings (Buhaug, 2010). For instance, several scholars have found that *rainfall scarcity* increases the likelihood of widespread civil war (Miguel et al., 2004) and subnational conflict (Fjelde & von Uexkull, 2012). In the same way, other scholars have argued that *rainfall abundance* increases conflict (Witsenburg & Adano, 2009), or similar to our findings, that rainfall variability has a curvilinear effect to civil conflict (Hendrix & Salehyan, 2012). In sharp contrast, recent studies have concluded that rainfall and natural disasters have little or no effect on conflict (Buhaug, 2010; Koubi et al., 2012).

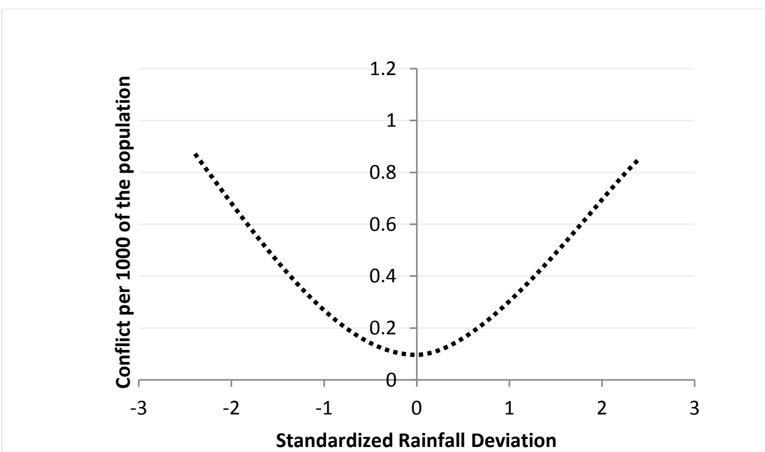
Moreover, past research on African pastoralist drylands has established correlations between both more and less precipitation and conflict. Concerning pastoralist areas two arguments oppose each other. Witsenburg and Adano (2009) argue that livestock raiding in Northern Kenya (Marsabit district) is more probable during wet seasons when pasture and water are abundant, when the livestock is in good health, and hence, the competition to access scarce productive areas increases. On the contrary, Ember et al. (2012), by applying the same methodology to a neighbouring district in North-western Kenya -i.e. the Turkana district, argue that rainfall scarcity leads to higher intensity of violence- drier months and drought years have higher intensities of violence.

Using the parameter of rainfall variability to assess the climate-conflict nexus, findings are more irrefutable now (Hsiang et al., 2013), and suggest that sharp rainfall deviations, on a subnational level, regardless of the sign of the rainfall variation, trigger conflict (Blakeslee & Fishman, 2014; Devlin & Hendrix, 2014; Hendrix & Salehyan, 2012; Raleigh & Kniveton, 2012; Theisen, 2012). In other words, rainfall should be perceived as a key climate variable in terms of its impact both on agricultural productivity and, as a consequence, on livelihoods.

2.3 Contextual conditions

In thinking about the possible mechanisms underpinning the climate-conflict nexus in colonial Nigeria, it is important to consider some of the underlying agro-ecological, economic and political conditions. The first condition is that the great majority of the Nigerian population during colonial times relied on rain-fed agriculture. This implies that rainfall shocks had a potentially dramatic and direct impact on food security. In terms of historical barriers to the internal transport of imported foodstuffs, this potential impact was almost certainly larger than it is today. The prime hypothesis is that *both* droughts and excessive rainfall have reduced the productivity of arable land and that, in addition, droughts have reduced the availability of fresh water. The hypothetical relationship thus takes a U-shaped form, as illustrated in Figure 1, and will be estimated accordingly (see Data and method section). Deviations from the long-term rainfall mean are thought to have increased the probability of violent clashes between or within communities over increasingly scarce resources (Detges, 2014; Fjelde & von Uexkull, 2012; Witsenburg & Adano, 2009).

Figure 1. *Rainfall Shocks & Conflict Intensity*



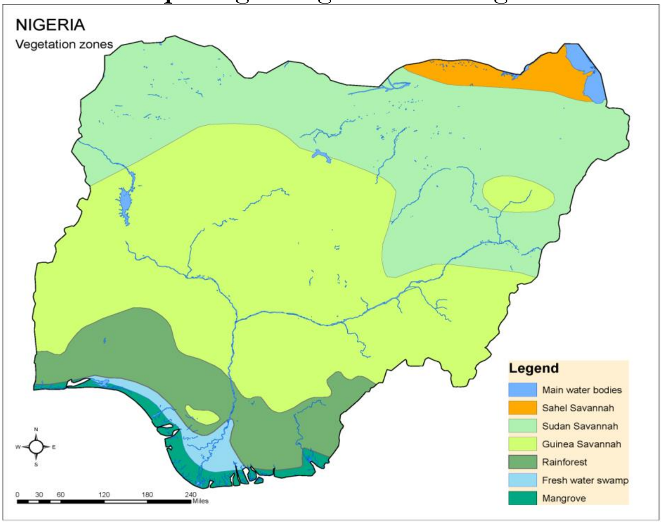
Source: Author's calculations. See main text.

The suggested climate-conflict relationship depends on many contextual factors. Although Nigeria lies entirely within the tropics, it covers different agro-ecological zones, characterized by different rainfall patterns (see Map 1). Since temperatures fluctuate much less in tropical than in temperate climate zones, seasonal cultivation strategies and crop-specific harvests tend to depend primarily on rainfall. Subsistence farmers, commercial farmers and pastoralists have come to specialize in different cropping systems in different agro-ecological zones; all of these variations have contributed to variegated conditions in terms of how people cope with climate-induced scarcities. For instance, livestock breeding broadens the opportunities to store wealth, mediate risks and increase land productivity. However, the presence of the tsetse fly has constrained cattle-keeping to only few parts of Nigeria.

The southern part of Nigeria stretches across the rainforest belt and the freshwater swamp zone. In this area, cash crops such as cocoa, palm oil, and tubers dominated agricultural production (Berry, 1975). In the northern part, which is the Sudan–Sahel savannah, groundnuts were the principal colonial export crop, especially in the heavily populated provinces of Kano, Zaria and Sokoto (Watts, 1983). Groundnuts were combined with millet and guinea corn for human and animal consumption. To the south of the Sudanese savannah, the Guinean savannah, food production was dominated by cereals, roots and tubers, along with a wide range of complementary food crops (Hopkins, 1973). In "normal" years, this area produced a surplus of cassava, yam, guinea corn and millet, which were traded to other regions of Nigeria. The colonial officials named this region the "Market Garden of Nigeria" (CO657/38, p. 72), because vast quantities of foodstuffs were exported to both the northern and southern provinces. We argue that the combination of highly vulnerable production systems in northern Nigeria, with a surplus area next door, increases the probability of widespread inter-communal conflict in cases of climate-induced scarcities in the North.

In political terms, colonial Nigeria can be divided into three different areas that correspond with the British administrative divisions of the country (see Map A-1, Appendix S1). The northern and western regions had established traditions of centralized power capable of exerting military influence and demanding allegiance and tribute from surrounding territories. The Muslim-dominated North was controlled by the long-established emirates of the Sokoto Caliphate, and was the largest region in terms of both area and population (Falola, 2009).

Map 1. *Agro-ecological Zones in Nigeria.*



Source: Iloeje & FAO 2001, created in ArcGIS.

The South can be roughly divided into two sections. In the West, a number of Yoruba kingdoms and the kingdom of Benin exercised changing degrees of central power. Although this region lacked political unity, states with sophisticated economic, political and cultural identities had already been developed since the 15th century (Iliffe, 1995). Their wealth was principally based on trade and tributes from subordinate territories (Hopkins, 1973). On the contrary, in the East, political authority rarely extended beyond the village level (Afigbo, 1972). The dominant group was the Igbo. This region was characterized, on the one hand, by some of the densest rural areas in sub-Saharan Africa and, on the other, by a lack of large centralized political units (Papaioannou & Dalrymple-Smith, 2015). The most significant problem that the British faced here was how to govern a territory that had no existing state apparatus by which they could induce local leaders to rule on their behalf. The colonial solution was the disastrous "Warrant Chief" system (Afigbo, 1972). The principle was that village chiefs would rule on behalf of the British. They were, according to the 1906 political report, to be "*selected from the most influential amongst the Native chiefs selected by the chiefs and people of the district and approved by the district commissioner*" (CO592/4, p. 314). The political structure of colonial Nigeria can thus be roughly summarized as a highly centralized structure in the North, compared to a semi-centralized south-western area and a completely amorphous south-eastern area.

These differentiated structures are essential to understand why areas reacted differently to the encroachment of colonial rule. Especially in areas with weak pre-colonial states, centralization resistance was endemic (Falola, 2009). It may thus be expected that the East and areas of the North outside the Emirates were more prone to conflict per se, even if these conflicts were unrelated to climate shocks. Moreover, in the centralized state structures of the North, which were characterized by higher social cohesion (higher local accountability) and stronger political institutions (state legitimacy and capacity), the British applied a more stringent version of indirect rule, in which the Islamic territories were granted a greater deal of autonomy (Watts, 1983).

Finally, there is empirical evidence that sees more politically centralized entities to be more coherent and less violent (Gennaioli & Rainer, 2007; Osafo-Kwaako & Robinson, 2013). The econometric results of this chapter show that in areas where the institutional arrangements were weak and did not extend beyond the village level, the competition over land and water was more severe, and led to higher levels of civil unrest. Whereas in areas where there was a central power capable of exerting its influence to other surrounding territories, climate shocks did not give rise to as many instances of conflict.

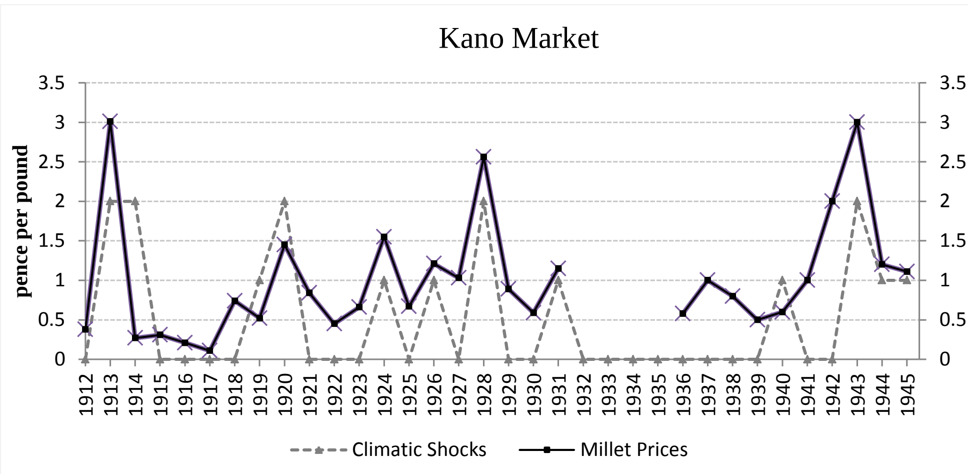
2.4 Plausible mechanisms

In discussing the plausible mechanisms that link climate shocks to conflict in colonial Nigeria, it is important to emphasize that extreme rainfall shocks may work in both directions, either through *negative rainfall deviations* leading to drought, potential crop failures and freshwater shortages, or through *positive rainfall deviations*, which can damage crops through flooding, mudslides or waterborne crop diseases. In a severe drought scenario, farmers and pastoralists may get into conflict over access to fresh water (Detges, 2014; Homer-Dixon, 1999). Rainfall shortages can have a direct effect on the number of farm animals, as a result of starvation or dying of thirst. Besides being a source of meat and milk, livestock is also indispensable for crop cultivation (for instance, ploughing, harrowing). A sharp decline in farm animals can thus have a detrimental effect on non-animal food supplies as well.

Even though rainfall surplus can be beneficial to farmers, extreme levels of rainfall are unwanted. Floods, mudslides or waterborne diseases can destroy harvests and part of the food stock for farm animals. The most notable waterborne disease in Nigeria was the "Black Pod Disease," which spread in the rainforest (cocoa zone) belt. This disease arises from exceptionally heavy and continuous rain usually during the months of July to September. For example, it occurred in 1933 in Ondo (rainfall deviation +2.03), where the losses sustained by farmers in this area were very heavy; it was estimated that more than 30 percent of cocoa was destroyed by this disease (CO657/36).

Another mechanism through which both types of rainfall shocks may lead to conflict is through increasing the *market price of food*. Food-price spikes can make food inaccessible, and even the mere expectation of (climate-induced) crop failures can drive up prices. Market prices of foodstuffs in Nigeria were subject to seasonal fluctuations and could be doubled within a year (CO657/40). Figure 2 illustrates how millet prices in Kano (northern Nigeria) were concurrent with climate-shock-related harvest conditions. Environmental security theory suggests that when societies face food shortages, price disputes emerge between rural producers and urban consumers increasing pressure on both sectors. The rising price of staple crops creates greater price inflation that undermines the purchasing power of urban dwellers (Berry, 1975; Hopkins, 1973). For instance, the *Agricultural Annual Report* of colonial Nigeria in 1915 observed that "*...the total production of main food crop –yams, maize and millet– in many parts of Nigeria was undoubtedly lessened by the shortage in the early rains…the shortage of rain had a serious effect on the crops...naturally the price of food in some of the larger towns has risen to an extent which could cause serious hardship*"(CO657/ 12, p. 17).

Figure 2. *Climate Shocks & Millet Prices*



Source: CO657/1-35.

A third mechanism that may instigate or aggravate conflict is the *migration* of people out of affected areas toward lesser-affected areas. Increasing demographic pressure can intensify the competition over food, water or land.[6] For example, during the severe drought spells of 1928 in the Sudanese Sahel, people from the North were forced to move southward, in the hope of finding uncultivated land and more favourable climatic conditions (Watts, 1983). Colonial officers observed many such movements, and stated that "*...an increase of 48,947 in the population is due*

[6] It is important to stress here that (a) not all migration movements lead to higher incidence of unrest and (b) not all climate shocks lead to higher levels of violence. The Nigerian historiography has been rich and filled with notable violent events that were not instigated by climatic conditions, such as the Egba rebellion against taxation in the West in 1918, or the Women's War in the East in 1929.

chiefly to the return of many who had migrated from the province (Kano) owing to failure of the harvest" (CO657/22, p. 46).

2.5 Cash crops: mitigating risk?

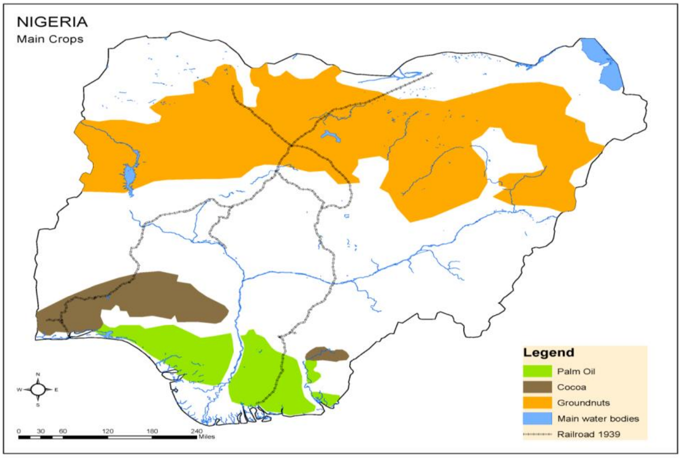
The extent to which specialization in cash crops has mitigated or aggravated the threat of climate-shock-induced conflict is prone to debate. In Vaughan's view (1987 pp. 9 and 77), "*Commercialization has distorted 'subsistence' economies and destroyed the insurance mechanisms in-built in these, without replacing them with any new form of security*" and "*this… [commercialization]…had had an inhibiting effect on production, village food stocks had been run down, and one bad season was enough to topple down the country into disaster*". In the same vein, Watts (1983) pointed out that the capitalist development (in particular, crop commercialization) in Nigeria created an unprecedented vulnerability to famines. Through a closely documented analysis of the peasant society for both the precolonial and colonial Hausaland, Watts portrayed the pre-colonial African subsistence economy as self-sufficient, autonomous and cooperative.

This view is supported by Richards (1990), who points out that there exist local (social) strategies that households follow in order to cope with hunger by requesting assistance from the members of a close kin. Repayment then is normally expected in the form of mutual assistance to households facing similar problems. A systematic attempt to model these mutual networks and solidarity in pre-capitalist societies has been put forward by Fafchamps (1992), who suggests that peasants would be willing to assist their kinsfolk because next year their luck may change and they too may need help from others. In the words of Evans-Pritchard (1940), "*it is scarcity not sufficiency that makes people generous*", which, in practice, suggests that informal solidarity mechanisms tend to emerge naturally, in cases of natural calamities where the economic and social conditions are substantially uncertain, and the survival of a household is endangered.

In this "moral economy", mechanisms and social systems were developed to insure local peasants against possible food disasters by having a "set price" for essential foodstuffs in the market. This price-setting implied that it was more important to a community to have a traditional "fair" price rather than a "free" market, where surpluses could be sold at a higher price. Raynaut (1977) stressed how the colonial rule profoundly disrupted social aspects of African farmers, as it changed long-established methods of distribution and circulation of vital foodstuffs among communities. According to Raynaut (1977), these methods were socially established and well respected within coherent collective groupings (families, ethnic and political units), and were disrupted by the introduction of cash crops, thus limiting the capacity of the African subsistence economies to withstand climate-induced food shortages.

On the other side of the debate, scholars have argued that crop commercialization provided the means not only to increase agricultural output but also to increase farmers' incomes, thereby limiting the vulnerability of cash-crop farmers to the vagaries of climate. For example, Gusten (1968) argued that cash-crop areas could support both their rural and urban populations, since most cash-crop farmers, especially cocoa farmers, did not abandon food crops when extending their cash-crop plantations (see Map 2).

Map 2. *Crop Commercialization in Nigeria*



Source: Iloeje & FAO 2001, created in ArcGIS.

In the same vein, Galletti et al. (1956) provided evidence from 187 families located around the cocoa belt in Southern Nigeria, which showed that 175 of them (almost 93 percent) produced some kind of food crop for consumption on the side, such as yams, maize and cassava (1956, pp. 410–411). Berry (1975, 170–171) stated that "...*the fact that the cocoa belt as a whole imports food-stuffs need not imply that cocoa has supplanted food crop production in these areas; it may instead reflect increased consumption, owing to growing population or to higher incomes, or both.*" She based her argument on the potential increasing benefits reaped from (inter-regional) trade, and on the diversification of domestic production, to conclude that economic specialization (that is, crop commercialization) limited the vulnerability of the cash-crop areas.

2.6 Data and method

To estimate the regression model, we use the system-generalized method of moments (system-GMM) developed by Bond et al. (2001), because it takes into account the time-series dimension of the data, the non-observable province-specific effects, a lagged dependent variable among the explanatory variables, and the possibility that all explanatory variables are endogenous (Roodman, 2006). The functional form of the dynamic panel model can be summarized as follows:

$$\text{Conflict\_variable}_{i,t} = \gamma\, \text{Conflict\_variable}_{i,t-1} + \beta_1\, \text{rain\_dev}_{it} + \beta_2\, \text{rain\_dev\_SQ}_{it} + \delta Z'_{it} + \nu_i + \mu_t + \lambda X_{it} + \varepsilon_{it} \quad (1)$$

$i = 1,\ldots, 20$ and $t = 1,\ldots, 34$

where $\text{Conflict\_variable}_{i,t}$ denotes the four different conflict variables in province i and year t. β_1 and β_2 are the coefficients of interest to be estimated. Z'_{it} is a vector of geographical, institutional and economic determinants of conflict -which need to be controlled for- measured during this period. Province fixed effects (ν_i) control for all time-invariant differences between provinces, and year fixed effects (μ_t) control for factors that may affect levels of conflict across all provinces in the same year; a good example of when higher incidences of conflict might be expected in a given year may be during the World War years, or years with extremely low export prices during the Great Depression.

Moreover, X_{it} denotes a province-specific time trend; that is, an interaction term between unobservable province characteristics (ν_i) and a linear time trend (t). In this way, we control for the possibility that (a) colonial authorities have become more efficient in inhibiting conflict over time, and (b) previous conflicts have promoted distrust among certain social groups, in such a way that this distrust may affect future attitudes and conflict intensity between particular groups. ε_{it} is the error term. To address autocorrelation concerns relating to climate shocks, the standard errors are clustered at various levels: the province level, the year level, and both the province and year levels.

The effect of climate shocks is estimated on four continuous dependent variables: the number of prisoners admitted during the year, the number of court cases, the number of homicides, and a newly constructed index named socio-political conflict (SPC), which combines the former three variables using principal component analysis. All of the dependent variables are standardized using provincial population estimates. The data were collected from the colonial bluebooks of statistics, administration reports and sessional papers from the National Archives in London.[7] Clearly a serious weakness is that these reports present only one side of the story (that of the colonizers). However, African accounts are unfortunately scarce. Therefore, when possible, we used secondary accounts and scholarship by African academics to corroborate the primary sources.

There have been cases where the figures are widely inaccurate, such as the population numbers, and noted by African scholars (Frankema & Jerven, 2014). The general consensus is that they are huge underestimates, as colonial demographers did not work extensively outside of large towns or settlements and

[7] The sessional paper and the administration reports provide detailed descriptive and statistical information on almost every aspect of colonial rule. Among the subjects covered are: the economy and public revenue; the judiciary and police; demographics; public works; agriculture and meteorological observations. The reports include many statistical tables, graphs, and maps. The Bluebooks collection provides a summary of the various statistics and returns which fall under the categories described above.

many people were understandably not keen on being counted, and therefore taxed. However, it also appears that the inaccuracies are fairly standard, and thus allow for at least a comparison of the relative populations of the different provinces under review. Despite that, we believe that the data used in constructing the two core variables (conflict and rainfall) should be seen with a degree of reliability. For example, the rainfall statistics were also used from the Agriculture and Medical departments for their own purposes, to either efficiently invest in experimental crop farms (e.g. cotton) or to associate them with outbreaks of malaria and other diseases. Similarly, the Prison and Criminal departments had to publish figures both for annual prisoners' admission and the reason of imprisonment, as well as the duration of imprisonment, indicating at least some attempt at accurate reporting.

Rainfall anomalies are measured as the *annual standardized rainfall deviation* from the long-term mean over the years 1912–1945. The data were collected from 36 meteorological stations across Nigeria on a provincial level documented in the Administration Annual Reports. Annual rainfall totals range from 120 inches in the South to less than 40 inches in parts of the extreme North (see Map A-3, Appendix S1). Even though we acknowledge the fact that one or two meteorological station(s) per province may not fully reflect the climatological conditions, we believe that the volume of data acquired -that is 34 years for over 20 provinces, resulting in a panel dataset with nearly 700 matching observations, increases the confidence in this study's findings. If any, we strongly believe that these inaccuracies down-bias our results.

The *rainfall deviation variable* is constructed using the following formula: $(X_{i,t} - \ddot{X}_i)/\sigma_i$, where $\ddot{X}_i$ is the long-term mean of each panel, $X_{i,t}$ is the annual rainfall in time t for province i, and σ_i is the standard deviation of each panel, that is, for every i. The rainfall deviation variable ranges from −3.46 to 3.68, and has a mean of almost zero and a standard deviation of 1. The advantage of the standardization of the variable is that it accounts for cross-provincial differences, as well as for within-province variation.

From an econometric point of view, we expect no endogeneity between the dependent and the main explanatory variable, as conflict cannot affect rainfall. We also expect a low risk of omitted variable bias, since it is highly improbable for any unobserved feature to influence both the amount of rainfall and conflict simultaneously. We employ three sets of controls in order to avoid potential omitted variable bias, and to increase the explanatory power of the model. These three controls are: institutional, geographical and economic.

(a) <u>Institutional controls</u>

Many studies have found a relationship between low (pre-) colonial centralization and various forms of resistance, hostility, agitation and political protest (Gennaioli & Rainer, 2007). We use a categorical variable [*political_structures*] to capture the variation across provinces, and expect a negative result. Easterly and Levine (1997) considered differences in ethnic fragmentation as a substantial explanation for divergences in political instability and conflict. We include a categorical variable of ethnic homogeneity [*ethnic_homogeneity*] to control for regional differences in ethnic composition. We also control for the imposition of direct taxation [*direct_taxation*] in 1929, which has spurred anti-colonial sentiments in various places. Finally, we control for the number of police staff [*police_staff*], which varied over time, as we expect that more police officers would have been assigned to politically instable provinces, and that part of their presence was related to tax collection.

(b) <u>Geographical controls</u>

We expect access (distance) to the sea [*coastal_distance*] to mitigate the impact of climate shocks by offering cheaper access to international trade (Gallup et al., 1999). Imports can mediate temporary shortages, and thus reduce conflict risks. Additionally, we include a categorical variable, [*agro-ecological_zones*], which ranges from 1 to 5, in order to control for differences in the resilience of agro-ecological zones to climatic shocks (Fenske & Kala, 2015; Seo et al., 2008). Finally, we include the coefficient of variation of rainfall [*cv*] in order to control for the possibility that a climate shock impacts differently on agricultural production in the northern provinces than in the southern ones.

(c) Economic controls

We expect that the construction of railways would reduce the potential magnitude of famines by opening up areas to food trades. While some scholars have argued that railway construction related merely to the exportation of goods, and may have been responsible for the 1913 famine in Kano (Apeldoorn, 1981), others have argued that it was used for food distribution policies. In either case, there is a possible link between railway construction and conflict intensity. We therefore assign a dummy variable to every province with a train station [*railway*].We control for levels of road density [*road_density*] following a similar reasoning, using a continuous variable of constructed roads for each province. Additionally, Herbst (2000) argued that higher investments in public infrastructure raise the opportunities for broadcasting state power. Hence, higher road-density levels can also be expected to be associated with quicker interventions by local police forces.

The presence of livestock [*livestock*] may mitigate the effects of scarcity in a particular province, by providing an alternative source of food. In the same vein, more diversified agricultural production, which can be achieved by cultivating cash crops on the side, may also mitigate the impact of climate-induced resource scarcity in a particular province and we therefore include a newly constructed variable [*Type_of_crop%*]. This variable was constructed by bringing together information from historical maps, offered by expert scholars in the field of West Africa, commodity production data from the colonial annual reports, and the use of GIS (see online Appendix S1 for more details). Finally, it may be that areas with larger populations and rapid demographic transformations are more prone to political disorder (Hendrix & Salehyan, 2012; Kahl, 2006); thus, two continuous variables ([*population_density*] and [*population_growth%*]) are used to control for these effects, respectively. In both instances, a positive correlation is expected.

Descriptive statistics of the variables used in the baseline and extended models are reported in Table 1. These statistics provide the context in which to assess the magnitudes of the econometric results.

Table 1. *Descriptive Statistics*

Variable	Obs.	Mean	Std. Dev.	Min	Max
Panel (a): Dependent Variables					
Conflict_index_SPC	512	0.008	1.000	-0.461	6.513
Prisoners_1000	620	1.103	2.059	0.004	15.344
CourtCases_1000	547	2.161	5.903	0.001	42.096
Homicides_1000	520	0.021	0.023	0.001	0.109
Panel (b): Independent Variables					
Rainfall_deviation	607	0.001	1.002	-3.351	3.102
Police_staff	603	162.816	203.801	0.000	940.000
Population_density	680	80.912	68.913	4.390	363.020
Population_growth (%)	660	1.820	14.589	-43.247	194.708
Agro-ecological_zones	680	2.600	0.970	1.000	4.000
Ethnic_homogeneity	680	0.670	0.141	0.400	1.000
Political_structures	680	2.300	0.781	1.000	3.000
Type of Crop (%)	680	0.351	0.477	0.000	94.500
Coefficient of Variation (CV)	680	0.207	0.044	0.131	0.294
Road_density	680	5.657	3.565	0.070	16.178
Coastal_distance	680	371.454	288.310	0.000	936.300

Source: see main text.

2.7 Empirical results

The first set of regressions is reported in Table 2. The rainfall deviation square is highly statistically significant in all specifications, and confirms a U-shaped association between all four dependent conflict variables and climate shocks. In all the regressions, we included lags of the main explanatory variable in order to test whether climate shocks in the preceding years (t-1) affect conflict at time t. A statistically significant correlation here would mean that extreme weather variability is not the main trigger of conflict. However, the estimated coefficients of those lags do not indicate any significance, which supports the argument that climate shocks almost immediately translate into higher levels of conflict.

The control variables behave largely as expected, and their significance levels remain consistent among different econometric specifications. The police variable yields a positive and statistically significant coefficient. Road density yields a negative and significant coefficient. Finally, population growth yields an expected positive and significant sign.

Table 2. *Conflict* & *Rainfall Deviation*

Dependent variable	(1)	(2)	(3)	(4)
	Conflict_Index_SPC	Prisoners_1000	CourtCases_1000	Homicides_1000
Lagged_dependent (t-1)	0.1771	0.1869	0.2109	0.1087
	[5.99]***	[2.58]**	[2.71]**	[1.89]*
Rainfall_deviation	-0.0221	-0.0819	-0.0797	-0.0232
	[-0.29]	[-1.53]	[-1.38]	[-1.41]
Rainfall_deviationSQ	0.1878	0.2691	0.3562	0.0428
	[2.36]**	[3.86]***	[4.58]***	[3.76]***
Rainfall_deviation, lagged(t-1)	0.1045	0.1071	0.1242	0.0968
	[1.37]	[1.56]	[1.34]	[1.05]
Rainfall_deviationSQ, lagged(t-1)	0.0766	0.1151	0.1007	0.0397
	[0.59]	[0.77]	[0.64]	[0.81]
Police_staff	0.0036	0.0038	0.0035	0.0011
	[4.13]***	[3.75]***	[4.83]***	[2.66]**
Road_density	-0.0621	-0.0536	-0.0317	-0.0792
	[-2.53]**	[-2.23]**	[-2.06]**	[-2.16]**
Population_growth(%)	0.0032	0.0025	0.0022	0.0019
	[2.30]**	[1.98]**	[1.84]*	[1.80]*
Geographical controls	Y	Y	Y	Y
Fixed effects	Y	Y	Y	Y
Time dummies	Y	Y	Y	Y
Province-specific effects	Y	Y	Y	Y
Number of Observations	484	522	522	498
Number of Provinces	20	20	20	20
Number of Instruments	27	28	29	28
AR1 statistics (p-value)	0	0	0	0
AR2 statistics (p-value)	0.296	0.318	0.378	0.348
Hansen test (p-value)	0.924	0.931	0.947	0.843

Notes: - System-GMM estimation for dynamic panel data-model. Sample period: 1912–1945.
- Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent.
- Second (and latter) lags were used as instruments in the first-differenced equations, and their once-lagged first differences were used in the levels equation.
- Two-step results using robust standard errors corrected for finite samples using Windmeijer (2005) correction.

- Time dummies, province-specific effects and a time trend are included in all regressions. Geographical controls include distance to the coast, distance to the nearest port, navigable river dummies, and the rainfall coefficient of variation (cv).

The findings are straightforward, and confirm a direct and causal impact of climate shocks on conflict. An example serves to highlight the potential magnitude that one particular climate shock had on conflict levels. Column 4 of Table 2 displays a positive correlation between the main explanatory variable (estimated coefficient: +0.0428) and the number of homicides per 1000 of the population, suggesting that an additional increase of rainfall deviation led to an average of 62.4 additional homicides.[8]

Columns 1-9 of Table 3 show the results of the baseline regression model, adding various control variables one by one.[9] The results show that the estimated coefficient of rainfall deviation squared remains positive and statistically significant in all specifications, confirming a robust U-shaped climate-conflict relationship (using the Conflict_index_SPC). The agro-ecological zone variable yields the expected positive effect, but is not statistically significant. The railway dummy yields a negative, but insignificant, correlation. Direct taxation yields an expected positive sign, but is statistically insignificant. The ethnic homogeneity variable yields the expected negative sign, and is significant. Additionally, the dummy for livestock is statistically significant, indicating that there seems to be less conflict in the Northern provinces of Nigeria, where the absence of the Tsetse fly allows for (more) cattle keeping. The significant estimated coefficient of political centralization indicates that in cross-region variation differing political structures suggest considerable explanatory power, and confirms the idea that politically centralized entities are more coherent and less violent.

In column 9 of Table 3, a dummy variable is included in order to assess whether provinces with cash-crop producers, as compared to subsistence farmers, have experienced different degrees of conflict under similar climatic conditions.

[8] The analysis was also carried out by normalizing all three conflict measures. It is reassuring that this transformation did not change the results in a significant way.

[9] This depicts a cautious way to avoid any multicollinearity bias in the estimate models. We used the variance inflation factor (VIF) test to assess the presence of multicollinearity; in all model specifications, no evidence of multicollinearity was detected.

The type of crop variable is statistically insignificant, and therefore is not further interpreted here; however, this distinction is further examined in the next set of regressions. Finally, in column 10 we have included all of the control variables described above in order to test whether the effect of climate shocks on conflict disappears via the joint inclusion of these controls. The results did not change in any significant way. Finally, we tested for cross-sectional dependence after each of the above-mentioned set of regressions, as suggested, by Conley (1999). The reason for this is that there may be a concern that shocks to one province may spill over into adjacent provinces, which could eventually provide inconsistent estimated coefficients. The results suggest that cross-dependence is not a major concern.

Table 3. *Conflict Index* & *Rainfall*

Dependent variable Conflict_Index_SPC	(1)	(2)	(3)	(4)	(6)	(7)	(8)	(9)	(10)
Conflict_Index_SPC, lagged (t-1)	0.1869	0.2109	0.1287	0.1766	0.2055	0.1679	0.2324	0.2114	0.1751
	[2.58]**	[3.71]***	[2.18]**	[2.74]**	[3.22]***	[2.81]**	[4.32]***	[6.09]***	[2.89]***
Rainfall_deviation	-0.0819	-0.0797	-0.0788	-0.0768	-0.0806	-0.0897	-0.0454	-0.0504	-0.0714
	[-1.53]	[-1.68]	[-1.41]	[-1.31]	[-1.43]	[-1.22]	[-0.82]	[-0.83]	[-1.03]
Rainfall_deviationSQ	0.2991	0.3062	0.3128	0.3221	0.3055	0.3044	0.2811	0.2718	0.2613
	[3.86]***	[4.58]***	[3.76]***	[3.75]***	[4.36]***	[4.19]***	[3.85]***	[3.32]***	[2.74]***
Rainfall_deviation, lagged(t-1)	0.1071	0.1242	0.0968	0.0959	0.1156	0.1101	0.1866	0.1545	0.1034
	[1.56]	[1.34]	[1.05]	[1.06]	[1.47]	[1.41]	[0.92]	[1.06]	[0.86]
Rainfall_deviationSQ, lagged(t-1)	0.1151	0.1007	0.1097	0.1009	0.1104	0.1054	0.0671	0.075	0.0987
	[0.77]	[0.64]	[0.81]	[0.61]	[0.78]	[0.73]	[0.63]	[0.73]	[0.54]
Police_staff	0.0038	0.0035	0.0029	0.0027	0.0037	0.0039	0.0031	0.0036	0.0027
	[3.75]***	[4.83]***	[2.66]**	[2.55]**	[3.68]***	[3.57]***	[4.66]***	[4.92]***	[3.11]***
Road_density	-0.0821	-0.0736	-0.0917	-0.0723	-0.0692	0.0319	-0.0529	-0.0431	-0.0248
	[-2.23]**	[-1.96]**	[2.16]**	[2.04]**	[-2.39]**	[2.08]**	[-1.71]*	[-2.14]**	[-2.09]**
Population_growth(%)	0.0018	0.0011	0.0022	0.0022	0.0019	0.0015	0.0013	0.0033	0.0028
	[2.05]**	[1.91]*	[2.01]**	[1.99]**	[1.88]*	[2.06]**	[1.85]*	[1.91]*	[1.94]*
Agro-ecological zones		0.1024							0.0824
		[1.24]							[1.31]
Railway			-0.1459						-0.1051
			[-0.55]						[-0.44]
Ethnic_homogeneity				-0.3107					-0.2156
				[-2.86]***					[-2.91]***
Livestock					-0.3998				-0.3011
					[-2.84]**				[-2.51]**
Direct_taxation						0.1902			0.1662
						[1.15]			[1.01]
Political_structures							-0.1063		-0.1433
							[-3.00]***		[-3.02]***
Type_of_crop (%)								-0.2418	-0.1319
								[-1.04]	[-0.98]
Geographical controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Fixed effects	NO	NO	NO	NO	NO	NO	NO	NO	NO
Time dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES
Province-specific effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Number of Observations	484	484	484	484	484	452	484	484	452
Number of Provinces	20	20	20	20	20	20	20	20	20
Number of Instruments	24	28	28	28	28	27	27	28	35
AR1 statistics (p-value)	0	0	0	0	0	0	0	0	0
AR2 statistics (p-value)	0.344	0.348	0.378	0.404	0.348	0.355	0.291	0.247	0.449
Hansen test (p-value)	0.854	0.931	0.947	0.928	0.917	0.982	0.917	0.817	0.921

Notes: Similar with Table 2.

2.8 Further explorations

This section will first outline the heterogeneous effects climate shocks have on conflict, conditional on geographical, institutional and economic characteristics; it will then investigate whether the climate-to-conflict effect is symmetrical. A large body of literature has emphasized the role of agro-ecological zones (Seo et al., 2008), pre-colonial structures (Osafo-Kwaako & Robinson, 2013) and crop commercialization (Watts, 1983) in shaping and explaining various instances of conflict.

2.8.1 Heterogeneous effects

Recent literature has suggested that some agro-ecological zones are less resilient to climate shocks than others (Kala et al., 2012; Seo et al., 2008). This body of literature emphasizes the supply-side of environmental shocks and suggests that the harvests of crops in less resilient regions can more easily be destroyed (Fenske & Kala, 2015). As a result, extreme climate shocks in these regions are more likely to jeopardize food security, raise resource competition over cropland and pastures, and trigger conflict.

In the case of colonial Nigeria, the Guinean savannah appears to be the most conflict-prone ecological zones, where communal conflict arose between the cattle-keeping Fulanis and the agriculturalists of the Guinean savannah over access to land. The Fulanis and their livestock drifted southward in search of water and food, which resulted in the destruction of the Guinean farmlands and spurred increased communal clashes. Even though there have been permanent tensions between farmers and herders, such issues have been more prevalent during years of higher rainfall deviations (Detges, 2014; Ember et al., 2012; Witsenburg & Adano, 2009). Our results support this argument.

Column 1 in Table 4 shows the results of the baseline regression with the inclusion of the AEZ categorical variable. The insignificance of the estimated coefficients of this variable does not confirm an environmental deterministic hypothesis; thus, different agro-ecological zone by themselves cannot explain cross-regional conflict variation. However, when they interact with rainfall deviations from the long-term mean (column 2), differing agro-ecological zones gain more explanatory power, and one of these zones -the Guinean savannah- yields a positive and statistically significant relationship with conflict. The Guinean savannah interaction term also yields the highest estimated coefficient (+0.4491).

In column 3 of Table 4, the significant estimated coefficient of the political centralization variable suggests that different political structures predict different levels of conflict. This finding corroborates with previous literature that sees more politically centralized entities to be more coherent and less violent (Osafo-Kwaako & Robinson, 2013). Furthermore, we include two interaction terms to capture whether different political entities react differently to the occurrence of climate shocks (column 4). It seems that there are more climate-induced conflicts in areas with weak pre-colonial institutions (in this case the eastern provinces), compared to areas with strong pre-colonial institutions (in this case the provinces around the Sokoto Caliphate).

In column 5 of Table 4, the results show that different types of crops do not account for conflict variation across provinces unless they are affected by a climatic shock. The dummy variable of food crop does not yield a significant correlation. In column 6, however, the estimated coefficients indicate that the provinces in which food crops are cultivated, while being affected by extreme climate shocks, witnessed higher levels of conflict compared to the cash-crop areas.

These results do not confirm the alleged disruptive and calamitous impact of crop commercialization on African farmers, and suggest that in the Nigerian case, the introduction of new cash crops neither destroyed the insurance mechanisms nor intensified the risk of food shortages. On the contrary, it seems that crop commercialization limited the vulnerability to climate shocks because it diversified production and income, which enabled farmers to reap the increasing benefits from inter-regional and international trade. This conclusion does not provide evidence with respect to whether crop commercialization was good or bad for the African farmers in the long run; rather, it argues that the vulnerability of the cashcrop areas was considerably reduced due to agricultural diversification.

Table 4. *Interaction Terms* & *Rainfall Deviation*

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Conflict_Index_SPC								
Conflict_Index_SPC, lagged (t-1)	0.2109	0.1645	0.2324	0.2354	0.1689	0.1619	0.2872	0.2751
	[3.71]***	[2.64]**	[4.32]***	[3.60]***	[3.50]***	[2.86]**	[5.23]***	[6.24]***
Rainfall_deviation	-0.0797	-0.0827	-0.0454	-0.0211	-0.0242	-0.0741		
	[-1.68]	[-1.38]	[-0.82]	[-0.29]	[-0.38]	[-1.29]		
Rainfall_deviationSQ	0.3062	0.2738	0.2811	0.4154	0.2525	0.1456		
	[4.58]***	[2.31]**	[3.85]***	[3.16]***	[2.68]**	[4.76]***		
Rainfall_deviation, lagged(t-1)	0.1242	0.1228	0.1866	0.0836	0.1545	0.1218		
	[1.34]	[1.06]	[0.92]	[0.47]	[0.53]	[1.26]		
Rainfall_deviationSQ, lagged(t-1)	0.1007	0.0965	0.0671	-0.0081	0.0519	0.1153		
	[0.64]	[0.75]	[0.63]	[-0.10]	[0.85]	[1.10]		
Police_staff	0.0035	0.0043	0.0031	0.0026	0.0034	0.0039	0.0018	0.0017
	[4.83]***	[2.93]***	[3.66]***	[2.24]**	[4.14]***	[4.95]***	[4.31]***	[3.19]***
Road_density	-0.0736	-0.0641	-0.0529	-0.0234	-0.0717	-0.0692	-0.0178	-0.0175
	[-1.96]**	[-1.79]*	[-1.71]*	[-2.21]**	[-1.89]*	[-1.80]*	[-1.44]	[-1.75]*
Population_growth(%)	0.0011	0.0091	0.0013	0.0037	0.0017	0.0011	0.0005	0.0001
	[1.91]*	[1.87]*	[1.85]*	[0.67]	[2.01]**	[1.88]*	[0.33]	[0.02]
Agro-ecological zones	0.1024							
	[1.24]							
Dummy_mangrove_swap								
Rainforest^		-0.5585						
		[-1.03]						
Dummy_rainforest		0.0467						
		[0.19]						
Guinean_Savannah^		0.4491						
		[2.33]**						
Dummy_Guinean_Savannah		0.4612						
		[3.99]***						
Sudan_Savannah^		-0.3964						
		[-1.76]*						
Dummy_Sudan_savannah		-0.2346						
		[-1.34]						
Political_structures			-0.1063					
			[-3.00]***					
West_medium_centralized^^				-0.1495				
				[-0.77]				
Dummy_medium_centralized				-0.1421				
				[-0.24]				

North_high_centralized^^				-0.1559				
				[-1.98]**				
Dummy_high_cenralized				-0.3785				
				[-2.44]**				
Food_crop (reference category)					-0.1091	0.1739		
					[-0.69]	[1.99]**		
Food_crop^^^						0.3735		
						[2.49]**		
Negative_climatic_shock (Drought)							0.1639	
							[1.94]*	
Positive_climatic_shock (Excessive)								0.2077
								[2.03]**
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Geographical controls	YES	YES	YES	YES	YES	YES	YES	YES
Fixed effects	NO	NO	NO	NO	NO	NO	NO	NO
Time dummies	YES	YES	YES	YES	YES	YES	YES	YES
Province-specific effects	YES	YES	YES	YES	YES	YES	YES	YES
Number of Observations	484	484	484	484	484	484	484	484
Number of Provinces	20	20	20	20	20	20	20	20
Number of Instruments	24	33	27	32	30	29	34	34
AR1 statistics (p-value)	0	0	0	0	0	0	0	0
AR2 statistics (p-value)	0.344	0.384	0.291	0.302	0.301	0.652	0.329	0.303
Hansen test (p-value)	0.854	0.927	0.917	0.958	0.977	0.923	0.971	0.926

Notes: - System-GMM estimation for dynamic panel data-model. Sample period: 1912–1945.
- Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent.
Second (and latter) lags were used as instruments in the first-differenced equations, and their once-lagged first differences were used in the levels equation.
- Two-step results using robust standard errors corrected for finite samples using Windmeijer (2005) correction.
- Time dummies, province-specific effects and a time trend are included in all regressions. Geographical controls include distance to the coast, distance to the nearest port, navigable river dummies and the rainfall coefficient of variation (cv). Controls include all variables used in Table 3.
- (^) denotes four interaction terms: mangrove swamp, rainforest, Guinean savannah and Sudan savannah.
- (^^) denotes three interaction terms: high, moderate and low centralized political structures.
- (^^^) denotes two interaction terms: cash- and food-crop provinces.

2.8.2 Symmetrical effect

The curvilinear (U-shaped) climate–conflict relationship is not fully symmetrical. Although the estimated coefficients in columns 7 and 8 of Table 4 are both statistically significant, their coefficients vary considerably. It appears that conflict has been more acute in wetter years (+0.208) than in drier years (+0.164). This result is in line with Theisen (2012) findings for Kenya. A possible explanation for this (perhaps somewhat counterintuitive) finding is that in years of excessive rainfall farmers would lose their entire harvest in a very short time (such as a couple of days), whereas in years of drought farmers could hope and wait for late rains. Therefore, in the former scenario farmers may be more directly concerned with survival and fighting than in a drought scenario, which results in an increase to the conflict time frame. Another possible explanation may be that excessive rainfall destroys infrastructure, particularly unpaved roads, thereby limiting the ability of colonial police patrols and military escorts to respond quickly to violence.

2.9 Qualitative evidence

In this section we back up our regression results with qualitative historical evidence. We use historical newspapers and government reports to explore food shortages, crop-price spikes and outbreaks of violence. We combine and triangulate data from these historical sources in three stages. First, by looking at the rainfall patterns of a particular year and indicating whether moderate and/or severe climate shocks occurred. For this, we follow the Standardized Precipitation Index classification (Wu et al., 2005) to categorize different-magnitude shocks into three groups: (1) when the deviation is more than ±1, it is considered to be a mild shock; (2) more than ±1.5 indicates a moderate shock; and (3) more than ±2 is seen as an extreme shock (see Appendix S1, Tables A-4a-c). Second, we use information from the annual agricultural reports from the colonial government to investigate whether these climate shocks actually led to deficient harvests and to crop-price spikes. Third, turning to those years and provinces which were severely affected, we read through the police, prison and military reports and use the statistics to back up the underlying mechanisms and hypotheses.

For the period 1912–1945, we documented 203 shocks in the whole of colonial Nigeria; 97 of these were owing to excessive rainfall, and 107 were due to mild, moderate or extreme droughts. Naturally, these shocks were not evenly spread out. In 1916, 1929 and 1935 there were no shocks of any serious magnitude. In 1913, on the other hand, the situation was disastrous, with extreme droughts extending across large parts of West Africa. It is worth noting that the colonial reports only recorded conflicts of major importance (CO657/17, p. 67); that is, outbreaks of violence that were a serious concern to the authorities as they potentially threatened the colonial social order. At the end of the harvest period the *Nigerian Pioneer* of September 4, 1913 mentioned: "*The absence of rain seems general throughout Nigeria, and is causing some uneasiness. Should there be no adequate rainfall during the later rains, the ensuing harvest will be of a poor description*" – a speculation that became true later that year. In 1913, there were many moderate and severe climatic shocks in several provinces. In Kano, for example, there was an extreme drought (rainfall deviation: –2.40). According to the Agriculture Report (CO657/1, p. 10): "*the rainfall during the year was abnormally low and, in consequence, agriculture suffered throughout the country, but more particularly in the province of Kano where the failure of the food crops caused a famine*".

The social consequences of this drought became visible in a sharp increase of prisoners and court cases during the year. The number of prisoners admitted to government jails in the Kano province was 455, as compared to 212 in 1912 (an increase of 114 percent) and 190 in 1911; 13 of these prisoners were incarcerated for debt, 39 for security reasons, and 403 were sentenced to penal imprisonment. Out of the total number of offenders serving sentences of penal imprisonment there were 288 for terms over two years, while the same figure during the preceding year was just 68. The military operations report of that year summarized that "*...a patrol was despatched to the Fagge district of the Kano Province in September, where inter-tribal fighting was taking place and some towns were reported to be in a state of anarchy. There were numerous casualties – 39 natives killed, and 7 wounded...*" (CO657/1, p. 32).

Looking back on the 1913 famine in Kano, Hastings (1925, p. 111) noted: "*...the ghost of famine stalked aboard through Kano and every other part. The stricken people tore down the ant hills in the bush to get the small grains and chaff within these storerooms* [...] *they made use of every poor resource their ingenuity could think of, and ravenous in their hunger, seized on anything they could steal or plunder* [...] *for the pasture had dried up and cattle were just skin* *and bone...*". This is a vivid description of what was happening in a province severely affected by famine. Local inhabitants, in need for food, plundered and stole everything in their way.

Turning to the local market conditions for buying food, Table 5 demonstrates the price spike for millet, which rose to an incredible high of 3d per pound (CO657/1, p. 45). Other grain prices in rural markets exhibited an increase of at least ten times above 1912 levels. The fact that millet prices, and prices of cereals in general, spiked dramatically meant that the vast majority of people were without food, or the means for obtaining it. The urban poor and other low-income groups must have suffered terribly due to food price inflation.

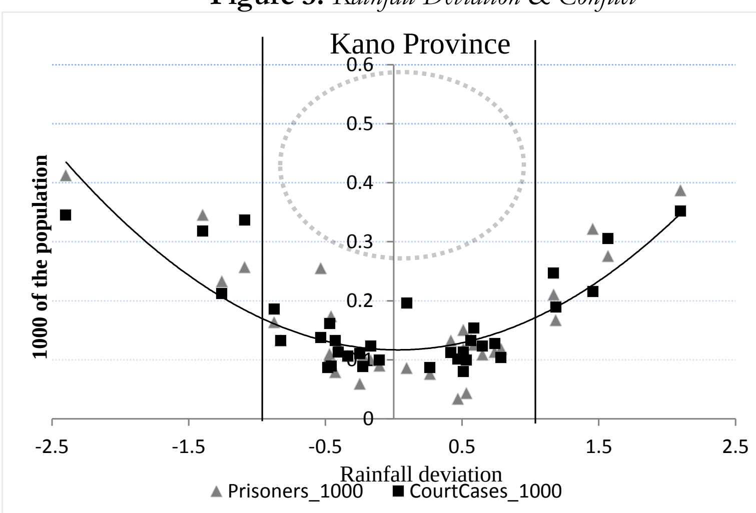
Table 5. *Cereal price data in Kano Market (millet)*

Year	Price (pence per pound)
1911	0.11
1912	0.38
1913	3.01
1914	0.27

Source: CO657/1

Figure 3 shows how rainfall deviation is related to a higher number of prisoners and court cases, whereas in "normal" years such levels were not recorded.

Figure 3. *Rainfall Deviation* & *Conflict*



Kano province was not the only area affected by the drought of 1913. In Bornu province (rainfall deviation: −1.65), a moderate drought also resulted in a severe food crisis. The lack of food supplies induced migration to other provinces –a trend confirmed by the population figures shown in Table 6. It seems that local inhabitants drifted southward, depopulating Bornu and seeking for more favourable climatic conditions, and relatively better lands to cultivate (see Table 6). However, for those who stayed behind, the Chief Commissioner of the native authority prison stated: "*there was an increase in the number of prisoners...this was due mainly to the growth of praedial larceny that last year's food shortage brought about*" (CO657/1, p. 69).

Table 6. *Population, Bornu province*

Year	Population
1910	674,000
1911	672,342
1912	513,388
1913	481,759
1914	626,500
1915	700,451

Source: CO657/1-4

The Bauchi province faced a moderate climate shock as well (rainfall deviation: −1.64). The police report noted that: "*a police patrol was sent to the Tangali District of the Bauchi Province, in November, to deal with a section of pagans who had set upon a native official and a peaceful village, killing 11 and wounding 12 of them. 9 of the aggressors had been killed and several wounded in the affray. 9 more were killed and 7 wounded when opposing the patrol*" (CO657/1, p. 53).

A systematic look at the reported judicial, prison population and criminal statistics reveals a high year-to-year variation in almost all provinces (see Appendix S1, Figure A-1). For instance, the judicial statistics show that in the aforementioned northern provinces the number of offenses against the police dropped from 2967 in 1913 to 2246 in 1914, and that the number of people brought before the Magistrates decreased from 2892 to 2190, a reduction of ca. 25 percent. The annual prisoners' report also confirms that the largest daily prisoner averages could be found in the Kano and the Bornu provinces in 1913 (CO657/1, p. 50).

After examining an extreme drought scenario, we will now focus on the variation between "moderate" years, and highlight outbreaks of violence following the three-stage approach discussed above. For instance, we will examine the two climate shocks in Ondo and Ogoja provinces in 1923, a year which, according to the colonial officials "*can be overall regarded as being a prosperous one regarding local farmers*" (CO657/9. p. 12). In Ogoja, the rainfall deviation of +2.14 marked a severe shock. The police report of 1923 stated that "*three escorts for major purposes*" had been sent to the province during the year, all of whom were accompanied by a high-ranked commissioner of the police. In particular, "*in July...a party of Bamenda traders en route from Ikom to Ogoja were brutally murdered on the main road when passing through the Bansara country..., an escort of 25 other ranks was despatched with the District Officer to investigate the matter. The result was that twenty people were arrested and returned for trial, several of whom were executed.*" Further, it was reported that "*other escorts for minor purposes were also supplied in the Ogoja province in September...in keeping the peace between the Afungbonga and Obubra tribes*"(CO657/9, p. 43). Crime statistics in the Ondo province (rainfall deviation: −1.74) recorded a substantial increase, "*where there were 15 murders as against none in the preceding year*," and the number of prisoners doubled from 205 to 417 (CO657/9, p. 44).

Another example is taken from the Kano province in 1920 (rainfall deviation: −1.56), where the reduced yield of groundnuts can be attributed to climatic causes: "*Kano farmers were unfortunate in experiencing a drought just after sowing, while subsequently the exceptionally heavy rains damaged the crop*"(CO657/6, p. 15). Moreover, the world market price for groundnuts was very low and would not bear the cost of transport from places far removed from the railway (CO657/6, p. 7). Turning to the criminal statistics of the year, the amount of stolen property was the highest ever recorded at £2.221. In the following year, Kano's figure for stolen property decreased by ca. 60 percent – lower than that of 1920 (CO657/6, p. 49).

The provincial report of 1926 in the Benue province (rainfall deviation: −1.87) recounted: "*there was a food shortage in several Benue Districts for a considerable part of the year, and unfortunately there is the possibility of a recurrence in 1927*," and continued "*...disturbances entailing the use of armed force occurred during the year...on one occasion an attempt was made to ambush the Political Officer.*" The *Nigerian Pioneer* of 30 March 1926 confirmed the prevalent disorder in the province: "*...a mob attacked the police station and the police were compelled to fire with the result that one rioter was killed.*" Additionally, in the Bauchi, where there was a significant drought (−1.51) in the same year, the number of provincial court cases increased by ca. 40 percent. The agricultural report noted that: "*famine conditions in some of the Northern provinces caused some distress...and food prices became greatly inflated*" (CO657/17, p. 14); further, "*the conditions were certainly not such as is conveyed by the word famine, but there was a definite shortage which caused the price of grain to soar to three or four times the normal price*" (CO657/17, p. 17). The consequences of these high food prices can be depicted through the annual police report of 1926, which noted that "*...of the seventy-eight offences of homicide in the whole of Northern Nigeria, fifty-nine were cases of murder. The very great majority of these cases, namely forty-four, occurred in the pagan districts of Benue and Bauchi provinces...*" (CO657/17, p. 107) –this represents a shocking 75 percent of the total registered murder cases.

The following two cases were selected to offer a comprehensive impression about the *temporal dimension* of the advent of climate-induced civil unrest. We argue that the majority of violent incidents usually occur during and immediately after the rainy season (June–September), when the farmers realize that their yields are going to be deficient or of a complete failure, and the opportunity cost for violent uprising declines. For instance, in Onitsha province (+1.73), the agricultural report summarized "*...the season was exceptionally wet. August and September proved to be together months of exceptional wetness, there being only about 3 days in each on which rain did not fall. Such an extraordinary wet spell proved fatal to the young crops. July was likewise wet enough to cause an unusual amount of rotting of the seed in the ground. The result was a crop failure and, it* *is probable that the year 1917 will be memorable for a serious failure of many crops*" (CO657/4, p. 8).

Turning to the police and criminal report of the year "*in early September...three police escorts were necessary to deal with unrest among the Ibeagu-Ezzi clan...it was known that the Ibeagu suffered 25 casualties*" (CO657/4, p. 88). Moreover, "*...a regrettable incident occurred in the Enugu Division late in September. Arising out of disputes over farming areas between the towns of Onicha-Agu and the Umunevu quarter of Amagunze...a chief of Onicha-Agu, who was a member of the Native Court, was murdered in the main street of Umunevu on his way home from court...9 ringleaders were murdered too*" (CO657/4, p. 91). Therefore, 34 homicides took place right after a severe crop failure, a figure which accounts for 85 percent of the total homicides (40) registered that year in Onitsha.

2.10 Conclusion

This chapter investigated the linkage between climate shocks and the incidence of conflict in colonial Nigeria. It makes several contributions to the current literature. We measured climate shocks through deviations from long-term rainfall patterns in a nonlinear (U-shaped) relation, capturing both drought and excessive rainfall, and introduced a new set of continuous conflict variables. We argued that climate shocks enhanced competition over scarce resources, which led to disputes and clashes on a smaller communal scale; in spite of their calamitous impact on civilian life and property, non-state communal conflicts have received limited attention in the literature to date.

To the best of our knowledge, this case-study is the first to provide both qualitative and quantitative evidence on climate-induced subnational conflict in a historical setting. It presents a considerable amount of detailed qualitative evidence, which adds robustness to the econometric results, and supports the suggested mechanisms leading from climate shocks to conflict in the context of colonial Nigeria. Finally, this chapter expands the existing research agenda to historical periods by merging the theoretical and empirical insights of the environmental security and the economic historical literature.

Overall, the results indicate that there exists a robust and significant relationship between rainfall deviations and conflict intensity, which tends to be stronger in agro-ecological zones that are least resilient to climatic variability (such as Guinean savannah), and where (pre-) colonial political structures were less centralized. There is evidence that the relationship is weaker in areas that specialize in the production of export crops compared to subsistence farming areas, suggesting that agricultural diversification acted as an insurance mechanism against the whims of nature.

Several long-term implications stem from the results of this chapter, and need to be further investigated. First, we need to retrieve previously unexplored archival data to measure climatic variability and conflict in a more precise way. There is scope for better understanding the climate-to-conflict relationship, by adding a substantial historical perspective. Second, we need to create a benchmark of the nature of violence by investigating how it changes over time and over the long run. This will enable us to draw safer conclusions for present-day outcomes. Has climate change been a recent phenomenon, or short term climatic variability instead has been responsible for higher outbreaks of conflict?

Third, we predict that future studies could explore the extent to which the introduction of new cash crops (such as cacao, tobacco, etc.) in Africa destroyed the traditional insurance mechanisms of farmers. Has the introduction of cash crops mitigated or aggravated the threat of climate-induced conflict over time? Have areas with a substantial cash-crop export sector performed better in declining poverty rates over the long run, compared to areas primarily dedicated to food crops? To conclude, the results from this chapter seem to suggest that crop commercialization provided the means to increase farmers' income through the additional benefits reaped from international and inter-regional trade, and in turn this diversified farmers' production and limited the vulnerability of the cashcrop areas to the vagaries of climate.

Appendix. Supplementary material

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.polgeo.2015.07.001.

Historical Sources

Statistical yearbooks and government reports

The Colony and Protectorate of Nigeria, Blue Book. Lagos: Government Printing Office, various issues, retrieved from The National Archives, London (Department code: **CO 657**, Series number: **1–56)**.

_____________ Annual Report. Lagos: Government Printing Office, various issues, retrieved from The National Archives, London (Department code: **CO 660**, Series number: **1–35**).

References

Afigbo, A. E. (1972). *The Warrant Chiefs: Indirect rule in southeastern Nigeria, 1891–1929*. Cambridge University Press.

Apeldoorn, G. V. (1981). *Perspectives on drought and famine in Nigeria*. Crow's Nest, New South Wales: George Allen and Unwin Press.

Bachler, G., Boge, V., Klotzli, S., Libiszewski, S., & Spillmann, K. R. (1996). Environmental degradation as a cause of war: ecological conflicts in the third world and peaceful ways of resolving them. Zurich: Ruegger.

Berry, S. (1975). *Cocoa, custom and socio-economic change in rural Western Nigeria*. Oxford University Press.

Blakeslee, D., & Fishman, R. (2013) *Rainfall shocks and property crimes in agrarian societies: evidence from India*. SSRN 2208292.

Bond, S., Hoeffler, A., & Temple, J. (2001). *GMM estimation of empirical growth models* (Vol. 3048). London: Centre for Economic Policy Research.

Buhaug, H. (2010). Climate not to blame for African civil wars. *Proceedings of the National Academy of Sciences*, *107*(38), 16477–16482.

Burke, M. B., Miguel, E., Satyanath, S., Dykema, J. A., & Lobell, D. B. (2009).Warming increases the risk of civil war in Africa. *Proceedings of the National Academy of Sciences*, *106*(49), 20670–20674.

Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S., & Ringler, C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological Economics*, *93*, 150–165.

Ciccone, A. (2011). Economic shocks and civil conflict: A comment. *American Economic Journal: Applied Economics*, *3*(4), 215–227.

Conley, T. G. (1999). GMM estimation with cross sectional dependence. *Journal of Econometrics*, *92*(1), 1–45.

Detges, A. (2014). Close-up on renewable resources and armed conflict: The spatial logic of pastoralist violence in northern Kenya. *Political Geography*, *42*, 57–65.

Devlin, C., & Hendrix, C. S. (2014). Trends and triggers redux: Climate change, rainfall, and interstate conflict. *Political Geography*, *43*, 27–39.

Easterly, W., & Levine, R. (1997). Africa's growth tragedy: Policies and ethnic divisions. *The Quarterly Journal of Economics*, *112*(4), 1203–1250.

Ember, C. R., Abate Adem, T., Skoggard, I., & Jones, E. C. (2012). Livestock raiding and rainfall variability in northwestern Kenya. *Civil Wars*, *14*(2), 159–181.

Evans-Pritchard, E. E. (1940). *The nuer* (Vol. 940). Oxford: Clarendon.

Fafchamps, M. (1992). Cash crop production, food price volatility, and rural market integration in the third world. *American Journal of Agricultural Economics*, *74*(1), 90–99.

Falola, T. (2009). *Colonialism and violence in Nigeria*. Indiana University Press.

Fenske, J., & Kala, N. (2015). Climate and the slave trade. *Journal of Development Economics*, *112*, 19–32.

Fjelde, H., & von Uexkull, N. (2012). Climate triggers: Rainfall anomalies, vulnerability and communal conflict in sub-Saharan Africa. *Political Geography*, *31*(7), 444–453.

Frankema, E., & Jerven, M. (2014).Writing history backwards or sideways: Towards a consensus on African population, 1850–2010. *The Economic History Review*, *67*(4), doi:10.1111/1468-0289.12041.

Galletti, R., Baldwin, K. D. S., Dina, I., & Board, N. C. M. (1956). *Nigerian cocoa farmers: An economic survey of Yoruba cocoa farming families*. Board by Oxford University Press.

Gallup, J. L., Sachs, J. D., & Mellinger, A. D. (1999). Geography and economic development. *International Regional Science Review*, *22*(2), 179–232.

Gennaioli, N., & Rainer, I. (2007). The modern impact of precolonial centralization in Africa. *Journal of Economic Growth*, *12*(3), 185–234.

Gleditsch, N. P. (1998). Armed conflict and the environment: A critique of the literature. *Journal of Peace Research*, *35*(3), 381–400.

Gusten, R. (1968). *Studies in the staple food economy of western Nigeria: With 32 maps*. Weltforum Verlag.

Hastings, A. C. G. (1925). *Nigerian days*. John Lane.

Hendrix, C. S., & Salehyan, I. (2012). Climate change, rainfall, and social conflict in Africa. *Journal of Peace Research*, *49*(1), 35–50.

Herbst, J. (2000). *States and power in Africa: Comparative lessons in authority and control*. Princeton University Press.

Homer-Dixon, T. F. (1999). *Environment, scarcity, and violence*. Princeton, NJ and Oxford: Princeton University Press.

Hopkins, A. G. (1973). *An economic history of West Africa*. London: Longman Group Ltd.

Hsiang, S. M., Burke, M., & Miguel, E. (2013). Quantifying the influence of climate on human conflict. *Science*, *341*(6151), 53–67.

Iliffe, J. (1995). *Africans: The history of a continent*. Cambridge University Press.

Johnstone, S., & Mazo, J. (2011). Global warming and the Arab Spring. *Survival*, *53*(2), 11–17.

Kahl, C. H. (2006). *States, scarcity, and civil strife in the developing world*. Princeton University Press.

Kala, N., Kurukulasuriya, P., & Mendelsohn, R. (2012). The impact of climate change on agro-ecological zones: Evidence from Africa. *Environment and Development Economics*, *17*(06), 663–687.

Klomp, J., & Bulte, E. (2013). Climate change, weather shocks, and violent conflict: A critical look at the evidence. *Agricultural Economics*, *44*(s1), 63–78.

Koubi, V., Bernauer, T., Kalbhenn, A., & Spilker, G. (2012). Climate variability, economic growth, and civil conflict. *Journal of Peace Research*, *49*(1), 113–127.

Miguel, E., Satyanath, S., & Sergenti, E. (2004). Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy*, *112*(4), 725–753.

Osafo-Kwaako, P., & Robinson, J. A. (2013). Political centralization in pre-colonial Africa. *Journal of Comparative Economics*, *41*(1), 6–21.

Papaioannou, K. J., & Dalrymple-Smith, A. E. (2015). Political instability and discontinuity in Nigeria: The pre-colonial past and public goods provision under colonial and post-colonial political orders. *The Economics of Peace and Security Journal*, *10*(1), doi:10.15355/epsj.10.1.40.

Raleigh, C., & Kniveton, D. (2012). Come rain or shine: An analysis of conflict and climate variability in East Africa. *Journal of Peace Research*, *49*(1), 51–64.

Raleigh, C., Linke, A., Hegre, H., & Karlsen, J. (2010). Introducing ACLED: An armed conflict location and event dataset special data feature. *Journal of Peace Research*, *47*(5), 651–660.

Raynaut, C. (1977). Lessons of a crisis. Drought in Africa, 2: 17.

Richards, P. (1990). Local strategies for coping with hunger: Central Sierra Leone and northern Nigeria compared. *African Affairs*, *89*(335), 265–275.

Rodney, W. (1978). *How Europe underdeveloped Africa*. Bogle-L'Ouverture Publications, Howard University Press.

Roodman, D. (2006). How to do xtabond2: An introduction to difference and system GMM in Stata. Center for Global Development working paper(103).

Seo, S., Mendelsohn, R., Kurukulasuriya, P., Dinar, A., & Hassan, R. (2008). Differential adaptation strategies to climate change in African cropland by agro-ecological zones. *Environmental & Resource Economics*, *43*(3), 313–332.

Sternberg, T. (2012). Chinese drought, bread and the Arab Spring. *Applied Geography*, *34*, 519–524.

Theisen, O. M. (2012). Climate clashes? Weather variability, land pressure, and organized violence in Kenya, 1989–2004. *Journal of Peace Research*, *49*(1), 81–96.

Vaughan, M. (1987). *The story of an African famine: Gender and famine in twentieth-century Malawi*. Cambridge University Press.

Voors, M., Van Der Windt, P., Papaioannou, K. J., & Bulte, E. (2016). Resources and governance in Sierra Leone's civil war. *The Journal of Development Studies*, 1-17.

Watts, M. (1983). *Silent violence: Food famine and peasantry in Northern Nigeria* (Vol. 18). Berkeley, CA: University of California Press.

Windmeijer, F. (2005). A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics*, *126*(1), 25–51.

Witsenburg, K. M., & Adano,W. R. (2009). Of rain and raids: Violent livestock raiding in northern Kenya. *Civil Wars*, *11*(4), 514–538.

Wu, H., Hayes, M. J., Wilhite, D. A., & Svoboda, M. D. (2005). The effect of the length of record on the standardized precipitation index calculation. *International Journal of Climatology*, *25*(4), 505–520.

CHAPTER 3

Weather Shocks & Agricultural Commercialization in Colonial Tropical Africa:

Did Export Crops Alleviate Social Distress?

Abstract

This study investigates how weather shocks triggered social distress in British colonial Africa. Further, it intervenes in a long-standing and unsettled debate concerning effects of agricultural commercialization on the abilities of rural communities to cope with exogenous shocks. We collect novel qualitative evidence from annual administrative records to explore the mechanisms that lead from weather extremes to harvest failures and, in turn, to social distress. For our econometric analysis, we construct a panel dataset of 151 administrative districts across west, south-central and east Africa in the Interwar Era (1920-1939). Our findings are twofold. First, we find robust evidence that rainfall anomalies (both drought and excessive precipitation) are associated with spikes in imprisonment (our proxy for social distress). We argue that the key causal pathway is the loss of agricultural income, which results in higher imprisonment for petty crime, civil unrest, debt and tax default. Second, we find that the impact of weather shocks on distress is partially *mitigated* by the cultivation of export crops. We argue that, even in a British colonial context, smallholder export crop cultivation led to higher private incomes as well as greater public investment. Our findings speak to a topic of considerable urgency today as the process of global climate change accelerates, generating more severe and unpredictable climatic extremes. We believe that increased understanding and identification of *adaptive* and *mitigating* factors would assist in targeting policy interventions and designing adaptive institutions to support vulnerable rural societies.

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3.1 Introduction

"*...the year had gone mad. Rain fell as it had never fallen before. For days and nights together it poured down in violent torrents, and washed away the yam heaps [...] The blazing sun returned, more fierce than it had ever been known, and scorched all the green that had appeared. The earth burned like hot coals and roasted all the yams that had been sown [...] He watched the sky all day for sign of rain clouds and lay awake all night. In the morning he went back to his farm and saw the withering tendrils.*"

Chinua Achebe, *When Things Fell Apart* (1994, p.16)

For centuries, many thinkers and scholars have sought to understand whether and how climatic conditions influence societies and the economy. Any understanding promises insights into why some economies have thrived *historically* while others languished, how *contemporary* societies can design effective policies and institutions to shield against current climate extremes, and how *future* climate change may impact human habitation. In recent years, a proliferation of rigorous studies has emerged aiming to quantify and assess the effects of climate extremes on economic and social outcomes (Hsiang et al., 2003; Dell et al., 2014). This surge can be explained, partly by rising public concerns about climate change and its potentially ensuing distortive effects on human development, partly by a greater popular awareness of the critical role climate might play in affecting social and economic outcomes, and partly by methodological advances and data availability, aided by developments in computing power.

The adverse impact of climatic variability on social outcomes has proven particularly pronounced in developing countries, with Sub-Saharan Africa (henceforth abbreviated to Africa) being the most vulnerable region. This does not come as a surprise, as a large share of the population depends on rain-fed subsistence agriculture, with less than 5% of the cultivated area being irrigated (FAO 2014). In such a context, climate-induced harvest failures appear to be tightly related to food insecurity, economic distress and social destabilization. Africa's rising population densities, pervasive climate change and resurging socio-political instability make this prolonged vulnerability to the vagaries of climate a most pressing concern (Morton, 2007).

While this growing body of research has demonstrated that climate extremes significantly impact societies, human affairs are not uniformly *determined* by climate. The effects of climate on the society are mediated by a wide variety of geographical, cultural, institutional and commercial factors (Sen, 1981; Thompson, 1971; Watts & Bohle, 1993). The key question, then, is which factors enable the *mitigation* of adverse impacts of climate extremes, and how such factors can be propagated through targeted policy interventions (Adger, 2000; Folke, 2006; Gallopin, 2006).

Whether agricultural commercialization aggravates or mitigates the vulnerability of rural communities is the subject of a multifaceted, heated and long-standing debate among historians, policy makers and social scientists (Von Braun & Kennedy, 1994; Govereh & Jayne, 2003). This study aims to use Africa's past experience with smallholder-based export production during the colonial era to generate new insights on the impact of agricultural commercialization on the abilities of rural communities to cope with weather shocks. We provide new district-level evidence on the link between weather shocks and social tension and distress in British colonial Africa during the interwar era (1920-1939), as well as on the mediating role of smallholder-based export crop production.

The data for our analysis have been compiled from annual *Colonial Blue Books* and *Administration Reports*, stored in The National Archives of the UK in London. Data was collected for over 200 sub-national administrative units in Botswana, Gambia, Ghana, Kenya, Nigeria, Sierra Leone, Tanzania, Uganda, Zambia. Exploiting the extensive and consistent administrative records that remain from Britain's African empire, we are able to provide new material on a world region for which systematic data collection is notoriously difficult, and, as a consequence, contribute to a considerable expansion of the historical time horizon.

Our research strategy has both a qualitative and econometric component. *First*, we critically examine the colonial administrative records to improve our understanding of the mechanisms that explain the impact of drought and excessive rainfall on harvest outcomes and distress. *Second*, we econometrically test the link between weather shocks and social distress, as well as the mediating impact of export crop cultivation. To that end, we obtain observations on annual rainfall and imprisonment, and construct a novel panel dataset at the sub-national level. We also construct two indicators to measure each district's involvement in export crop cultivation. To measure social distress, we use annual fluctuations in imprisonment at the district level. While colonial prisons locked people up for a wide range of distress-related behaviours, such as debt, tax and fine default, petty thefts and civil disobedience (Bernault, 2007; Hynd, 2008), imprisonment spikes in the wake of weather shocks provide us with a particularly valuable inroad to capturing social distress.

Justification for our selection of interwar British colonial Africa is made on a number of grounds. First, Britain administered a vast African empire. The extensive bureaucratic legacy has allowed us to construct a consistent district-level dataset, spanning approximately one-fifth of Africa's landmass and one-third of its population in this period. Second, the geographic and temporal scope provides data for over 200 sub-national administrative units. In some of these units, crops were grown on a considerable scale for export, while in others agricultural production was primarily geared towards subsistence. Our temporal scope encompasses the interwar period, a period of relative calm between the violent early-colonial conquest and the highly politicized post-war road to independence (Killingray, 1986).

Our qualitative evidence suggests several different mechanisms through which both drought and excessive rainfall result in harvest failures, adversely affecting agricultural incomes and provoking distress. The econometric estimates for our full sample, using fixed-effects models, confirm this relationship and reveal a robust *U-shaped* impact of weather shocks on different measures of imprisonment. The effect is not symmetrical. A 'negative rainfall shock' (drought), measured as a one standard deviation decrease from the long-term rainfall mean, is associated with 16.0 per cent increase in total imprisonment, and a 'positive rainfall shock' (excessive rainfall), measured as a one standard deviation increase from the long-term rainfall mean, is associated with an even stronger 24.8 per cent increase in total imprisonment. These effects are similar in magnitude to accumulated evidence from other studies reviewed by Hsiang et al. (2013). The results are robust to using two different indicators of annual rainfall anomaly, as well as range of alternative formulas for parameterizing rainfall shocks.

Having established a robust overall relationship between rainfall anomalies and annual spikes in imprisonment for our full dataset, we test if this relationship is mediated by smallholder-based export crop cultivation. The results show that a one standard deviation change in rainfall (in either direction) is associated with 10.2 percentage points change in total imprisonment in districts with substantial export crop production, as compared to 33.9 percentage points change in districts with negligible or no export crop production. This finding suggests that imprisonment spikes in districts with relatively high amounts of export crop income per capita were significantly less affected by weather shocks. We argue that this finding indicates commercialization of smallholder agriculture did have a *mitigating* effect on rural communities' vulnerability to weather shocks. The fact that our findings pass a wide range of robustness tests, increases our confidence in the actual production of export crops playing a crucial role in mitigating the impact of weather shocks.

The remainder of the paper is structured as follows. Section 2 places our study in the context of several related literatures. Section 3 introduces our qualitative evidence on the link between climate extremes, loss of agricultural income and distress. Section 4 discusses the data for our econometric analysis. Section 5 econometrically demonstrates a causal link between rainfall and imprisonment. Section 6 econometrically demonstrates that export crops mitigate the effect found in section 5. Section 7 discusses the implications of our findings and concludes.

3.2 Related Literature

3.2.1 The Impact of Climate on Economy & Society.

Over the past decade, the scholarly debate on the impact of weather anomalies on societal outcomes has expanded considerably. Scholars and policy makers have become increasingly aware of the short-run and long-run impact of climatic factors on a wide range of economic, social and political outcomes. The goal of this sub-section is not to systematically report all studies in this rapidly expanding literature, but rather to provide a brief contextual overview of the links between climatic fluctuations and key research trends. For a more profound summary on the new climate-economy literature, we encourage readers to consult Dell et al. (2014) for a general discussion, Burke et al. (2014) for conflict outcomes, Deschenes (2014) for health outcomes, Auffhammer et al. (2013) for climatic modelling, and Hsiang (2016) for nuances on climate econometrics.

While some scholars dispute the evidence linking weather to conflict outcomes (Klomp & Bulte, 2013; Buhaug et al., 2014), a range of studies have found that climatic variability not only triggers conflict (Fjelde & von Uexkull, 2012; Hendrix & Salehyan, 2012; Papaioannou 2016a), crime (Iyer & Topalova, 2014; Blakeslee & Fishman, 2015; Papaioannou, 2016b), and full-blown civil war (Blattman & Miguel, 2010), but also processes of democratization (Brückner & Ciccone, 2011). Scholars are divided on the mechanisms that explain the 'climate-society nexus' (Almer & Boes, 2012; Buhaug, 2010), but harvest failures are found to be a prime candidate, especially in settings where people's incomes rely heavily on rain-fed farming and where small fluctuations in crop yields can have devastating effects on livelihoods (Barrios et al., 2010; Iyer & Topalova, 2014; Blakeslee & Fishman, 2015; Miguel et al., 2004; Schlenker & Lobell, 2010; Papaioannou, 2016b).

Recent contributions have begun to investigate different time periods (Papaioannou, 2016a; Jia, 2014), employ a more fine-grained, sub-national scope (Harari et al., 2013; Raleigh & Urdal, 2007) and use more non-binary indicators as the dependent variable (Papaioannou, 2016a; 2016b). Moreover, a number of studies have employed detailed case study analyses to uncover the key mechanisms leading from weather variability to social distress, civil unrest and political upheaval (Adano et al., 2012, Benjaminsen et al., 2012; Ember et al., 2012; Witsenburg & Adano, 2009). Among those who take precipitation as the key independent variable, some find that drought is the prime reason for societal destabilization (Couttenier & Soubeyran, 2011; Maystadt & Ecker, 2014), while others argue that both droughts and excessive rainfall fuel higher social tension (Papaioannou, 2016a; Papaioannou, 2016b; Fjelde & von Uexkull, 2012; Hendrix & Salehyan, 2012).

The effects of climate extremes on local societies are not uniformed nor predetermined, but instead mediated by geographical, cultural, institutional, commercial factors (Sen, 1981; Watts & Bohle, 1993). In the words of E.P. Thompson, social unrest should not be seen as a mere "spasmodic" response to adverse conditions, and "a bad harvest, or a down-turn in trade" are not in themselves sufficient explanations of social outcomes (Thompson,1971). The key question, then, is which factors mitigate the impact of weather shocks, and how such factors can be propagated through targeted policy interventions. The mitigation of vulnerability to climate extremes has been a key priority issue in recent literatures investigating sustainable rural livelihoods (Chambers & Conway, 1992; Ellis, 1993; Scoones, 2009) and adaptive strategies to cope with climatic variability and change (Adger, 2000; Folke, 2006; Gallopin, 2006; Ahmed et al., 2009).

Our contribution here is fourfold. Firstly, we use qualitative evidence to explore the *mechanisms* running from weather shocks to social distress. Second, our dependent variable (imprisonment) is *continuous* and *fine-grained*, and allows us to pick up relatively minor fluctuations in social distress in the wake of these shocks. Third, we provide *new data* on a historical period that is so far understudied. Fourthly, and most importantly, we econometrically test for the *mitigating* effect of agricultural commercialization on vulnerability to weather shocks.

3.2.2 Agricultural Commercialization & Weather Shocks in a Colonial Context.

It seems obvious that agricultural production systems play a particularly crucial part in determining societies' abilities to cope with exogenous shocks. However, the ways in which agriculture may enhance the resilience of African communities, in a context of erratic and changing weather conditions, has been a particularly contentious issue among scholars and policy makers (Bryceson, 2002; Collier & Dercon, 2014; Giller et al. 2009; Raikes & Gibbon, 2000). Evidence on the impact of agricultural commercialization on resilience to weather shocks is mixed. On the positive side, increased openness to external markets has been associated (a) with higher incomes, and (b) with farmers' improved abilities to 'smooth consumption' and diminish short-term risks (Burgess & Donaldson, 2010; Fafchamps, 1992; Myint, 1958). Agricultural commercialization has also been argued to provide rural communities with access to new crops, inputs and agricultural technologies and to incentivize governments to invest in infrastructure, famine prevention and extension services, each with the potential to alleviate feasible adverse effects of volatile climatic conditions (Govereh & Jayne, 2003; Maxwell & Fernando, 1989). At the same time, scholars have drawn ample attention to the fact that market access is far from a uniform blessing to vulnerable rural communities. When attention is diverted from subsistence production, production for markets may induce hunger and malnutrition, while commercialization may result in the erosion of 'traditional insurance mechanisms', induce stratification, and facilitate external exploitation and extraction, each of which in fact makes societies more vulnerable to weather-induced shocks (Bates, 1981; Scott, 1976; Vaughan, 1987; Von Braun & Kennedy, 1994; Watts, 1983).

The literature on African history has exposed numerous mechanisms that influence the effect of export-based agricultural commercialization on distress in the wake of weather shocks. We do not claim to test the validity of the individual mechanisms proposed on either side. Instead, we take a previously underexplored angle and methodology and empirically test the '*weighted*' or '*net outcome*' of the variegated mechanisms running from export crop cultivation to vulnerability to weather shocks. In statistical terms, we tease out an '*average*' or '*overall treatment effect*' of export crops on types of distress that resulted in imprisonment in interwar British colonial Africa.

While we argue that our findings have broader implications and are relevant for contemporary debates on agricultural commercialization, it is also important to acknowledge the particular context from which our results are drawn. The volume of agricultural exports expanded markedly during the era of colonial rule (~1880-1960) (Tosh, 1980). In many cases, colonial rulers attempted to introduce or expand export crops through coercion and exploitation. In some, such as Kenya or Zimbabwe, settlers expropriated land and barred African smallholders from producing the most profitable crops (Mosley, 1980). In others, such as Mali, Congo or Mozambique, rural communities were forced to cultivate and sell crops for export rather than subsistence (Isaacman, 1980; Roberts, 1996; Likaka, 1997). However, uniformly equating the 'export crop revolutions' in early twentieth century Africa with colonial exploitation would not do justice to the agency and initiative of African smallholders (Tosh, 1980; Austin, 2014a).

The expansion of cocoa production in Ghana and Nigeria was driven by African rural capitalists (Hill, 1982; Austin, 2014b), while the expansion of commercial groundnut production in the Gambia and Northern Nigeria, as well as the introduction of tobacco and cotton in Uganda, Tanzania and Malawi, were conditional on the productive choices of millions of African rural households (Bryceson, 1981; Hogendorn, 1978; Mandala, 1990, Swindell & Jeng 2006; Wrigley, 1959). In northern Nigeria, smallholders massively took up groundnuts, while British colonial interests preferred to see cotton exported (Hogendorn, 1978). The cultivation of cotton in Uganda and groundnuts in the Gambia were primarily driven by indigenous agents, and their cultivation attracted scores of migrants from across the colonial borders (Swindell & Jeng, 2006; Wrigley, 1959)

A number of characteristics were common to the great majority of export crop cultivating smallholders during the colonial era. Firstly, they were cultivating in a *land abundant* context, in which labour was the primary factor constraining further expansion (Austin, 2008). Secondly, farmers continued to cultivate food crops and to pursue food self-sufficiency (Tosh, 1980). A typical cotton growing household in eastern Uganda, for example, only devoted 2.5 out of its total 8.0 acres cropped annually to cotton, and the remainder to food crops such as millet and groundnuts, primarily for home consumption (De Haas, 2016). Cocoa farmers in Nigeria and Ghana were, perhaps, the exception to this rule, due to the high profitability of cocoa, although even they cultivated considerable amounts of food crops alongside their cocoa trees (Austin, 2014b). Thirdly, export crops were cultivated with basic technology (hand cultivation, few external inputs and mostly unimproved seeds) (Tosh, 1980). As a result, yields were typically modest, but at the same time, smallholders did not have to incur large debts in order to participate in export crop cultivation. In some cases, export crops were explicitly 'state sponsored', and inputs such as cotton seeds or coffee seedlings were freely distributed.

While the introduction and expansion of export crops in British colonial Africa may not have exclusively, or even primarily, been driven by colonial policies, smallholders' productive choices were undoubtedly shaped by colonial occupation. Even though households were not formally obliged to cultivate crops in most cases, they were often pressurized to do so by chiefs and local administrators, or subjected to indirect force by the required payment of colonial taxes to market their produce (Wrigley, 1959; Bryceson, 1988; Mandala, 1990). Therefore, colonial state interventions may well have prevented some of the potential gains of agricultural commercialization from accruing to rural producers themselves.

Colonial rule also affected the spatial distribution of agricultural commercialization. In some areas, the introduction of motorized transport and new agricultural technologies under colonial rule may have enhanced the productive capacities of rural producers, while in others, it is possible that the lack of investment, the outmigration of young men and the introduction of taxes spurred rural impoverishment, contributing to a deepening of regional inequalities. This possibility suggests that, without colonialism, these districts would have benefited even more from agricultural commercialization, or that districts culminating in marginalized subsistence economies during the colonial era would have fared better if colonial states had made more efforts to increase their access to external markets.

Our finding that regions growing export crops are more resilient to weather shocks, begs (rather than answers) further questions about the interfering role of colonialism. For now, we simply face the reality that there is no empirical counterfactual at hand to answer such questions (Heldring & Robinson, 2012).

3.3 Qualitative Evidence

3.3.1 Weather Shocks, Harvest Failures and Social Distress

Our sources provide a unique opportunity to engage with the different perspectives on the debate over the effects of weather anomalies on rural African societies. The British colonizers set up a hierarchically organized system of administration in their African dependencies. Territories were subdivided into provinces and districts. The maintenance of law and order was largely left to African policemen, prison guards and native authorities, who operated as 'indirect rulers' under the supervision of British administrative officers. Elaborate administration accounts were kept, and local officials reported on a regular basis to their supervisors on a range of issues. We use annual administrative reports obtained from the departments of agriculture, native affairs, police, justice and prisons. These reports are consistent in their coverage of issues over time and across colonies, giving us a uniquely comprehensive insight into local conditions across a wide area and a timespan of 20 years.

The reports are rich in relevant content. At the same time, we must be aware of the colonial context in which these reports were produced. British colonial services tended to be understaffed, and local administrators' accounts reveal strong prejudice and paternalistic and derogatory attitudes towards local populations. On top of that, previous scholars have pointed out that civil servants, in order to inflate their achievements and benefit their own careers, had incentive to focus on 'progress' and paint a rosy picture to superiors, which may compromise some of the reliability of local administrative accounts (Killingray, 1986). We read the reports critically, and argue that some statements in the colonial reports can be more readily accepted than others. For example, an agricultural officer describing the impact of drought on seed germination seems to us more unproblematic than a district commissioner attributing starvation to "*the apathy of an ease loving people*" (Sierra Leone 1923), or an episode of social unrest to the "*idleness and nomadic instinct*" of the groups involved (Kenya, 1933).

The impact of weather conditions on agricultural outcomes is extensively discussed by colonial administrators, who make regular note of weather-induced agricultural failure, resulting in higher levels of distress. Both too little and too much rainfall are routinely proffered as causes of depressed agricultural incomes. ***Droughts*** are frequently mentioned as a catalyst for suppressed yields. In severe cases, drought is also associated with complete crop failure, dust storms and soil erosion. For instance, the agricultural report of 1920 Gold Coast states that the food crops in Volta River "*were exceedingly scarce*" as "*the drought during the early part of the year is causing many of the crops to fail and all crops realised high prices*." (Gold Coast, *Agricultural Report* 1920). Similarly, in 1927, the commissioner of Zaria District (Northern Nigeria) noted that the "*considerable decrease* [in foodstuffs] *is accounted for by a drought which occurred after planting had taken place*" which made it "*impossible for peasants to cultivate their land*" (Nigeria, *Provincial Report* 1927).

Diminished water supplies to wells, surface water sources and pastures, also associated with lack of rainfall, negatively impacts upon livestock. To prevent starvation, people moved with their livestock, which in turn increased their susceptibility to disease and further weakened underfed herds. An administrative account discusses how these varied drought effects simultaneously struck Baringo District (Kenya): "*The year 1933 has been one of the worst in living memory. A complete failure of the long rains caused enormous losses among stock, ruined the crops in the low-lying parts and made the harvest on Masop very late. It is safe to say 50 per cent of the cattle died*" (Kenya, *Native Affairs* 1933).

Regular mention is also made of the adverse effects of ***excessive rainfall*** on agriculture, running via different mechanisms. Heavy precipitation and resulting floods damaged crops and created adverse conditions for harvesting, storage and transportation of agricultural produce. In 1936, the Rufiji District (Tanzania) suffered "*a great flood*", which "*destroyed the main crops of one-third of the population*" (Tanganyika, *Native Affairs* 1936). Similarly, "*a truly phenomenal rainfall*" in Owerri Province "*severely injured the crops*" and led to "*widespread shortage of available food supplies*" (Nigeria, *Agricultural Report* 1922). In The Gambia, as a result of abnormally heavy rainfall, the groundnut crop "*suffered severely during the ripening and reaping period.* [...] *Fermentation was rapid and much damage was done to the nuts and to the quality of soil. The extent of this damage was widespread and felt throughout the country*" (The Gambia, *Agricultural Report* 1927).

Administrative accounts also link heavy rainfall to increased prevalence of plant diseases. In Ondo Province (Nigeria), 'black pod disease' destroyed an estimated 30 percent of the cocoa harvest during a year of heavy rainfall (Nigeria, *Agricultural Report* 1933). Reports also recount how parasitic organisms thrived under conditions of heavy rainfall. A serious increase in weevil infestation in the Trans Nzoia District (Kenya) was attributed to "*abnormal*[ly wet] *weather conditions*" (Kenya, *Agricultural Report* 1930).

Examples of the negative impact of droughts as well as excessive rainfall on agriculture can be found in both very wet and very dry regions. That positive and negative rainfall shocks compromise agricultural outcomes in a wide range of agro-ecological settings makes sense, considering that smallholders built their farming systems around an expected rainfall pattern. The choice of the crop mix and farming methods were calibrated on the basis of this expectation. Similarly, the physical environment was also conditioned by an expected level of rainfall. While lots of rain may seem beneficial to a dry savannah, its soils may be incapable of absorbing the precipitation, resulting in run-off, floods and waterlogging. For example, Machakos (Kenya), a district with an average annual rainfall of only 40 inches, experienced an exceptionally wet year after a number of consecutive years of drought. A colonial officer noted that "*despite the very heavy rain during the year, the condition of the Reserve has not improved; it has in fact degenerated further, particularly in regard to water supply. Owing to large areas being denuded of grass, the erosion caused by the heavy rains must have been enormous*" (Kenya, *Native Affairs* 1930).

The administrative accounts frequently link the adverse impact of rainfall to food price spikes and subsequent social distress, which took the shape of increased petty crime and livestock raids and thefts. In Northern Nigeria in 1927, "*the rainfall, which was considerably below the average, caused a partial failure of the guinea corn and yam crops in certain districts of the province. There was a definite shortage which caused the price of grain to soar to three or four times the normal price* [from 0.12 to 0.65 pence per bag]" (Nigeria, *Provincial Report* 1927). The district commissioner concluded that "*with the high prices which prevailed the native had a hard time to make both ends meet and a certain amount of distress has been apparent.*" The police report of that same year reported that "*petty theft was frequent in Kano. About April petty theft reached alarming proportions and special efforts were made to combat it.*" The annual imprisonment rates exhibited an increase of about 61%, forcing the Commissioner to state that "*there is no doubt that the reason for the increase of crime is mainly economic*" (Nigeria, *Police Report* 1927).

Examples like the one above can be drawn systematically from the sources. The native commissioner of Turkana district, a pastoral area in Kenya, pointed out that the shortage of water and grazing resulting from a drought in 1929, "*led to more migration and possibly more squabbles, crime and bloodshed than usual*" (Kenya, *Native Affairs 1930*) Only four years later, "a phenomenal drought" led to "famine and poverty" as well as a "co*nstant anxiety of raids and massacres on the frontier.* [...] *The*

Turkana have been driven in unprecedented numbers to encroach on the grazing and water supplies of their more fortunate neighbours" (Kenya, *Native Affairs* 1933). In that same year, the severe drought and resultant stock mortality in the Masai District (Kenya) "*led to an increase in crime. Actual hunger caused many sheep thefts and raids into Tanganyika Territory. Counter raids have proven serious.*" The local imprisonment rate of the year exhibited a sharp increase from 255 to 408 convicts (Kenya, *Native Affairs* 1933). The Kenya police report of 1933 points out that "*stock theft shows a 60 per cent. increase in the number of cases brought to court, while the number of persons convicted has nearly doubled. This large increase may be attributed to the difficult times experienced by the natives owing to the failure of the rains*" (Kenya, *Police Report* 1933).

An episode of abnormally high rainfall in Saltpond and Winneba District (Gold Coast) resulted in crop damage, failure and 'resultant stress', 'shortage of the food supply' and high prices. The incarcerated population increased by 25% and 37%, respectively (Gold Coast, *Agricultural Report*, 1925). In Rufiji District (Tanganyika) in 1930, "*for a considerable period 15,000 natives were homeless owing to the floods and many lost their houses, stock and crop.*" The local police commissioner noted that "*there was an increase of cattle theft, perhaps due to the shortage of food*" and that "*cases of theft predominated*" mainly owing to the food shortage. The number of thefts rose to 1028 compared to 600 the previous year – an increase of approx. 71% (Tanganyika, *Native Affairs* 1930).

Conversely, colonial officers sometimes also explicitly attributed the absence of tension and distress to low prices due to favourable weather, which can be assumed to have positively impacted food production. The Gambia police, for example noted that

> "with such favourable weather conditions coupled with the low price of foodstuffs, it was only to be expected that the crime figures should be satisfactory and never in the past 30 years has the total number of reports of serious crime been so small as in

> 1934. It is too much to hope that such a peaceful state of affairs can become normal" (Gambia, *Police Report* 1934).

While we find such causal inferences by colonial officials more plausible and satisfactory than the essentialistic assessments of the local population's 'natural responses' to adverse conditions mentioned above, we should still receive them with a degree of scepticism, since attributing social tension and distress to exogenous weather variation also conveniently diverted attention from the potential negative impact of colonial interventions themselves.

3.3.2 Cash Crops & Vulnerability

Our study of the administrative record highlights that the impact of export crops on resilience in the wake of exogenous shocks was already a contested issue among colonial administrators. A southern Nigerian agricultural director expressed the concern that cocoa "*considerably reduced the output of food*", and increased smallholders' vulnerability to weather anomalies. An episode of "*great shortage of food*" was attributed "*partially to the cocoa boom and partially to the drought*" (Nigeria, *Agriculture* 1930). Likewise, the agricultural commissioner of Gold Coast stated in 1921 that "*with the successful development of cocoa-growing there has been a marked tendency to neglect the cultivation of foodstuffs and to depend on imported provisions. In an essentially agricultural country this is not satisfactory or what one might expect. In the same interior districts a shortage of foodstuffs is actually felt.*" He argues that the shortage of food crops became so pronounced that "*the value of local grown products has soared to unheard of prices in recent years*," leading to "widespread distress" (Gold Coast, *Agriculture* 1921).

Other colonial administrators were more optimistic, highlighting the diversification of risk that came with the adoption of export crops. A drought in Central Kavirondo (Kenya) "proved disastrous to food crops", while the cotton crop "*fared better* [...]. *The failure of the food crops accentuated the value of cotton, for those who had it to sell were able to subsist on their own resources*" (Kenya, *Agriculture* 1937). In addition, several native officers of Tanganyika reported that farmers only began cultivating export crops "*when they had ensured for themselves and their dependents an adequate food crop*" (Tanganyika, *Native Affairs* 1930). The colonial officers also noted that smallholders prioritized food security over cash income, as "*the planting of food crops is the first consideration*" and that "*poor rains very often cause unavoidable delays in the planting of export crops such as cotton with the result that low yields are obtained*" (Tanganyika, *Native Affairs* 1933).

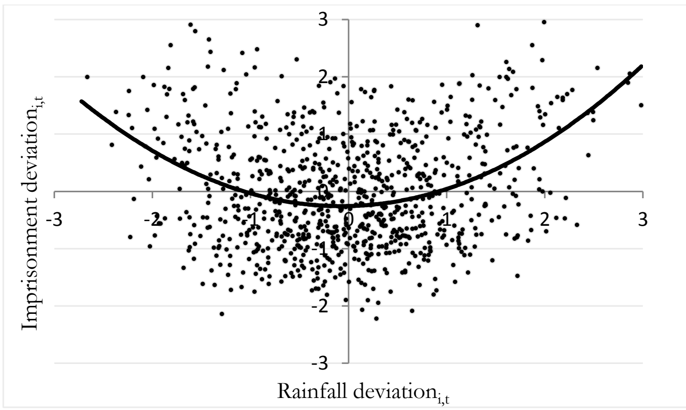
While we find that colonial reports are rather unambiguous when it comes to the adverse impacts of negative and positive rainfall shocks on agriculture and, with some reservations, social tension and distress, we conclude that the reports are more ambiguous and problematic when it comes to the adverse impact of weather shocks. This ambiguity in the colonial sources reflect similar ambiguity in the scholarly literature. We conclude that the reports are insufficiently impartial and too imprecise to provide us with much guidance in the process of assessing how export crop adoption affected the vulnerability of rural districts to weather fluctuations.

Previous studies have used unpublished correspondence, fieldwork or oral history to probe beyond, and provide a counterweight to, the biases and limitations inherent in colonial administrative records. The labour intensive nature of such in-depth research has confined most studies to one particular colonial territory or district. We opt for a different research strategy by collecting quantitative data covering a wide geographical scope for econometric analysis. While we acknowledge that a wide range of, potentially opposing, mechanisms will underpin our overall findings, and that such mechanisms deserve full attention of scholars and policy makers, we find it equally worthwhile to draw up the balance, and take stock of the *overall treatment effect* of export crops on social tension and distress.

3.4 Data

Our key variables of interest are imprisonment (the number of individuals admitted in year t) and rainfall (annual precipitation in inches in year t). We standardize both variables by computing their z-scores. Figure 1 provides a simple scatter-plot of the standardized rainfall anomalies against standardized annual imprisonment. Without any additional econometric testing, the figure brings out the non-linear (U-shaped) relationship between the two variables for the full sample. In other words, when rainfall deviates from the expected mean in either direction, the number of imprisoned individuals also spiked. We further explore this relationship econometrically in section 5 and include our export crop interaction effect in section 6.

Figure 1. *Weather Shocks* & *Social Distress in British Africa*



Notes: Both indicators are the result of 'standardizing' process using the z-score computation: $(x_{i,t} - \bar{x_i}) / \sigma_i$, where $\bar{x_i}$ is the long-term mean of each district, $x_{i,t}$ is the annual observation in time t for district i, and σ_i is the standard deviation of each panel, that is for every i.

All variables, including our *observable* and *unobservable* controls are discussed below. Summary statistics are provided in Table 1.

3.4.1 Rainfall

To measure rainfall shocks, we use annual precipitation data from meteorological stations. The great majority of districts under British rule contained at least one such station. Our main explanatory variable is the *absolute* value of standardized rainfall deviation from the long-term mean (*Absolute*R*ainfallDeviation*$_{i,t}$), which yields comparable results with the current economic literature (Hsiang et al., 2013; Dell et al., 2014). In order to capture the non-linear effect of rainfall shocks on imprisonment, we also present the results using the rainfall deviation square term (*RainfallDeviationSquare*$_{i,t}$). We also employ drought and excessive rainfall dummies, defining 'negative rainfall shock' as a dummy which takes the value of 1 when annual rainfall exceeds more than one standard deviation below, and 'positive rainfall shock' as one standard deviation above the long-run mean. This approach is similar to Iyer and Topalova (2014), Blakeslee and Fishman (2015) and Jia (2014), among other. The summary statistics of the weather indicators are presented in panel (*b*) of Table 1.

Table 1. *Summary Statistics: District by Year Data*

Variable	Obs.	Mean	Std. Dev.	Min	Max
Panel (a): Dependent variables					
Prisoners deviation	2714	0.00	1.00	-2.60	3.70
Debt deviation	2076	0.00	1.00	-1.70	3.50
Conviction for less than 3 months	2671	0.00	1.00	-2.30	3.80
Conviction for more than 3 months	2672	0.00	1.00	-2.80	3.90
Panel (b): Independent variable of interest					
Rainfall long-term mean Stations	2900	46.91	24.12	15.80	144.10
Rainfall deviation Stations	2529	0.00	1.00	-3.20	3.30
Rainfall deviation squared Stations	2529	1.00	1.32	0.00	10.89
Absolute rainfall deviation (Linear) Stations	2529	0.80	0.58	0.00	3.30
Rainfall long-term mean (Matsuura and Wilmott)	3200	47.01	21.73	12.70	139.70
Rainfall deviation. (Matsuura and Wilmott)	3200	0.00	1.00	-3.50	3.30
Rainfall deviation squared (Matsuura and Wilmott)	3200	1.00	1.33	0.00	12.25
Absolute rainfall deviation (Linear) (Matsuura and Wilmott)	3200	0.81	0.58	0.00	3.50
Negative rainfall shocks	2529	0.17	0.38	0.00	1.00
Positive rainfall shocks	2529	0.18	0.38	0.00	1.00
Export crop *production* value(£) per capita	3220	0.52	1.47	0.00	10.10
Export crop *suitability* (FAO-GAEZ)	3220	3.57	0.12	3.09	3.86
Food crop suitability (FAO-GAEZ)	2680	2.73	0.16	2.12	3.17
Panel (c): Control variables (time-varying)					
Population density (persons per square mile)	3260	52.98	74.60	0.13	801.44
Whites per 1000 of the population	3240	5.28	20.37	0.00	395.10
World market prices of relevant export crops	2176	100.76	40.12	31.00	303.00
Panel (d): Control variables (time-invariant)					
Rainfall coefficient of variation (CV)	2900	0.21	0.07	0.10	0.40
Pre-colonial chiefdom (Murdock)	3180	2.45	0.94	1.00	4.00
Railway dummy	3260	0.41	0.49	0.00	1.00
Settler agriculture dummy	3260	0.17	0.37	0.00	1.00
Cocoa cultivation dummy	3260	0.07	0.26	0.00	1.00
Coastal dummy	3220	0.18	0.38	0.00	1.00
Livestock units per 1000 of the population	3260	706.27	2197.98	0.00	24528.70

Source: See main text.

Our annual rainfall indicator does not capture the effects of years of normal annual rainfall with unfavourable distribution as well as years with below or above annual rainfall in which the abnormal precipitation occurred outside the growing season. Despite these limitations, we find the use of annual data largely unproblematic. The use of annual rainfall data is widely accepted in the economic literature (Miguel et al., 2004; Hsiang et al., 2013; Dell et al., 2014). Moreover, using annual rainfall figures for over ~2,500 observations is unlikely to result in a type I error (finding a relationship when there is none), but rather to underestimate the effect. A concern with our collected rainfall data could be that historical records have a tendency to suffer from under-reporting and observer's bias (Daly et al., 2007). Such bias may distort an annual total appear as a drought, when there really was none. To address such concerns, we sought to replicate our results with rainfall data obtained from the University of Delaware dataset (Matsuura & Wilmott, 2009), which has been corrected for measurement bias.

3.4.2 Imprisonment

We collect annual district-level data on total imprisonment (including remand prisoners), as well as three subcategories: (1) short imprisonments (3 months or less), (2) long imprisonments (>3 months) and (3) imprisonment for debt. Each district we include in our dataset has at least one prison within its borders. If more than one prison was present, we take the sum. Unfortunately, we do not possess specific information about convictions for different types of offenses. Yet, we argue that the convictions for petty property offences and tax and fine defaults dominate the short imprisonments, whilst violent offences are likely to be much more prevalent among the long imprisonments. Following Blakeslee and Fishman (2015) and Papaioannou (2016b), who find that property crimes respond more strongly to economic distress than violent crimes, we expect the 'short imprisonment' variable to be more responsive to weather shocks than the 'long imprisonment' variable.

It is important to state upfront that our research design (1) does not (intend to) capture variation in *absolute levels* of imprisonment across colonial districts, and (2) does not imply that colonial imprisonment should be attributed primarily to harvest failures, let alone climate. Colonial coercive capacity varied considerably from place to place (both across districts and colonies), and incarceration happened to an extent at the discretion of local administrative officers or native authorities. Colonial imprisonment was an instrument of social control, used to lock up criminal, deviant and destitute elements of society, including debt, tax and fine defaulters (Bernault, 2007; Branch, 2005; Hynd, 2008; Killingray, 1986).

Within this context, we can exploit *annual fluctuations* of imprisonment to assess the impact of rainfall extremes on distress. If weather extremes result in loss of agricultural income, and if people have no buffer to cushion this loss of income, we may expect a rise in behaviours and activities that result in imprisonment, including: (1) incidences of distress-induced petty property theft (cf. Papaioannou, 2016b), (2) tax, debt and fine defaults resulting in imprisonment (Hynd, 2008); and (3) rebellion and civil disobedience in responses to the fact that rulers prove unable to provide people with a basic level of security and income. Note that our interpretation explicitly accounts for the fact that behaviours resulting in colonial imprisonment may not have been perceived as 'criminal' by African populations, and that we consistently use the descriptive term 'imprisonment' rather than the more contentious 'crime'.

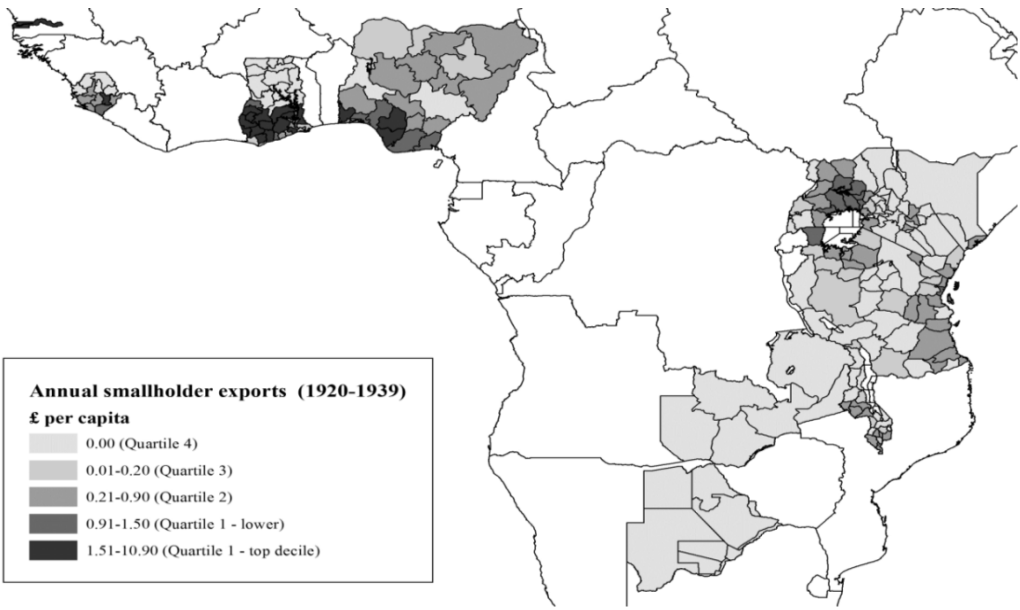
We exploit the following logic to test if weather shocks have a different impact on social tension and distress (i.e. imprisonment) in districts with smallholder-based export crop cultivation compared to districts without. When, in a particular district, imprisonment spikes are pronounced during years of weather shocks (i.e. inflated numbers of debt, tax and fine default, petty thefts and incidences of civil obedience), we take this as an indication that this district is particularly vulnerable to such shocks. If, in another district, imprisonment spikes are mild or absent in years of weather shocks, we take this as an indication that people were able to (1) prevent a fall in agricultural income, for example by cultivating a more diversified or weather-resistant crop portfolio, or (2) cushion the impact of such a fall, for example through the presence of a food relief campaign, or the availability of savings to compensate for falling income. More discussion on potential mechanisms is provided in the conclusion.

We are aware that imprisonment is an imperfect measure of social distress. Males were strongly overrepresented in Africa's colonial prisons, so we are unfortunately not able to capture the gendered impact of weather shocks, which is a particularly regrettable omission considering women's crucial role in agricultural production (Carswell, 2003; MacKenzie, 1999; Vaughan, 1987). Similarly, our data also does not allow us to assess the heterogeneous impact of weather shocks on different social classes or occupational groups. Finally, we have no information about the exact reasons of imprisonment. Despite these limitations, the variable also has its own pronounced strengths. Imprisonment figures are highly responsive to small fluctuations, and the data is uniquely consistent over a considerable geographical and temporal scope. Moreover, we have no reason to believe that the link between annual rainfall and imprisonment statistics was somehow the result of systematic and purposeful manipulation by colonial officials (who could not have fathomed that future research would use yet-to-be-developed econometric techniques to investigate the relationship between rainfall shocks, imprisonment and export crops). Our quantitative results, therefore, are much less susceptible to the kind of colonial manipulation that biases the narrative record.

3.4.3 Export Crop Production

To measure the impact of agricultural commercialization on vulnerability to weather shocks, we have constructed a new indicator to estimate *export crop production* at the district level. This indicator is based on the average value (1920-1939) of colony-level exports of export crops (Frankema et al., 2015), divided over the districts within the colonies on the basis of colonial maps and smallholder acreage and production estimates that tell us where export crops were cultivated. We standardize the values using district population estimates. More details are provided in Appendix B. Figure 2 shows the value per capita of smallholder-grown export crops for each of the districts in our dataset, divided into four quartiles (and the top decile separated from the remainder of the first quartile). The spatial distribution resulting from this exercise is in accordance with our expectations. Smallholder export crops in interwar British colonial Africa were concentrated in the Gambia (groundnuts), coastal Gold Coast (cocoa), coastal Nigeria (cocoa and palm oil), northern Nigeria (cotton and groundnuts), the Lake Victoria area (cotton and coffee), coastal Tanganyika and Zanzibar (cotton, copra and cloves) and southern Nyasaland (cotton and tobacco). As expected, the cocoa growing regions in Ghana and Nigeria produce the highest export values per capita.

Figure 2. *Export Crop Production*



Sources: Map constructed by the authors in ArcGIS on the basis of digitized colonial maps. See online Appendix 2 for further information.

In the remainder of our analysis, we split our dataset in halves, the bottom half representing districts in which smallholder production was subsistence oriented, and the top half those in which smallholders cultivated significant amounts of export crops. We have made sure that our results are not driven by a random cut-off point by using alternative cut-off points, quartiles and trimmed samples. Still, we admit that the distinction between "export" and "subsistence" districts is rudimentary. Some districts which did not cultivate crops for export were involved in the commercial production of food crops for local markets. For example, Carswell (2003) argues that smallholders in Kigezi District (Uganda) cultivated 'food crops as export crops'. We maintain, however, that the income from commercialized food crop cultivation tended to be small compared to income from export crops, for the following reasons: (1) marketing infrastructure in the colonial era was geared towards export and not interregional food trade, (2) markets for food crops were small due to low urbanization rates and land-abundance, (3) universal cultivation of food crops resulted in low market value in good years and food scarcity in bad years (Binswanger & McIntyre, 1987; De Janvry et al., 1991). The main source of income in non-export crop districts tended to be labour migration to more commercialized areas. Our dataset also includes some districts which were dominated by settler agriculture, urban centres or mining areas, for which we control in our analysis (by excluding them from subsamples). While measurements on the district level may brush over within-district variation, our approach is much more refined than most contributions covering similarly large areas and distinguishes 'peasant' and 'settler' economies at the country level (Bowden et al., 2008; Moradi & Baten, 2005), and even classifies Africa into macro-regions (Amin, 1972).

To provide more robust evidence for the *causal* impact of export crop cultivation, we construct an alternative export crop indicator which is exogenously determined. This indicator is based on *crop suitability indices* for the most important export crops (cocoa, coffee, cotton, tobacco, palm oil, groundnuts and coconuts) obtained from the FAO-GAEZ project. This suitability index runs from 1 (most suitable) to 8 (least suitable). Similar to other studies that have successfully exploited the exogenous nature of the crop suitability indicators to proxy for adoption or production of various types of crops (Nunn & Qian, 2010; Jia, 2014; Fenske & Kala, 2015), we take the average of the gridded suitability values within the borders of each colonial district. We construct our indicator by combining all relevant export crops, using the average suitability for all export crops for each districts.

Using export crop suitability should increase our confidence that institutional factors drive our results. However, districts which were more suitable to export crops may have been those with generally more suitable land, better soil and more favourable rainfall patterns. To rule out the possibility that our indicator of export crop suitability captures general agricultural suitability (which may in its own right result in higher weather-shock resilience), we also construct an indicator of food crop suitability, equally based on FAO-GAEZ data. We include, maize, millet, sorghum, cassava, yam, potato, sweet potato and rice, and follow a similar procedure as described above for our export crop suitability indicator.

3.4.3 Control Variables

We include a number of time-variant controls, reported in Table 1, panel (d). *Firstly*, annual total population is estimated on the basis of colonial 'native' census data, and expressed in terms of population density (per square mile). White population per 1000 of the population is estimated on the basis of 'non-native' censuses. World market prices of relevant export commodities are taken from Wageningen African Trade Database (forthcoming). *Secondly*, we include a range of observable time-invariant controls, reported in Table 1, panel (e). Pre-colonial centralization is based on the variable "Jurisdictional Hierarchy beyond Local Community" in Murdock's ethnographical atlas. Pre-colonial chiefdoms and states are defined as places with more than one level of jurisdictional hierarchy beyond the local community. Livestock per 1000 of the population is estimated on the basis of the district averages of livestock censuses (1920-1939). We use observable time-invariant controls to control for the interaction of several observable district-specific characteristics with a linear time trend to take into account their heterogeneous impact (if any) over time. For example, districts with high presence of livestock may become more (or less) resilient in 1939 than in 1920, due to stock accumulation.

Thirdly, we use unobservable time-invariant controls, reported in Table 1, panel (f). This set of controls is estimated by interacting each district with a linear time trend and labelled district-specific effects (DSE). They control for any other unobservable characteristics that we may expect to change over time, such as the possibility that (a) colonial authorities extended their coercive capacity over time (Branch, 2005); (b) previous episodes of distress have made districts more vulnerable, affecting future responses to weather shocks; (c) regions with higher incomes are better off over time because they are able to store wealth; and (d) distress may have been attenuated by the gradual expansion of public infrastructure such as roads and railways, facilitating food relief programs.

3.5 Results: Rainfall & Imprisonment

3.5.1 Model

To test the effect of rainfall shocks on social distress, we estimate the following specification:

$$\begin{aligned} Y_{i,t} = {} & \beta_1 \, AbsoluteRainfallDeviation_{i,t} + \delta Z'_{i,t} + v_i + \mu_t \\ & + (observable \times time)_{i,t} + (unobservable \times time)_{i,t} + \varepsilon_{i,t}. \end{aligned} \tag{1}$$

where $Y_{i,t}$ denotes the annual standard deviation of imprisonment. $AbsoluteRainfallDeviation_{i,t}$ denotes the absolute rainfall deviation of each district i from the historical long-term mean of the same district. $Z'_{i,t}$ denotes a vector of institutional and economic determinants of tension which we control for in order to avoid any potential omitted variable bias. ν_i and μ_t are district and year fixed effects, respectively. We use these to control for omitted heterogeneity at the level of districts and time periods. These controls are crucial in controlling for factors that may affect the levels of prisoners across all districts in the same year, such distress caused by the Great Depression. To address autocorrelation concerns of weather shocks the standard errors are clustered by district.

Moreover, *(observable × time)*$_{i,t}$ denotes the *observable* district specific characteristics when interacted with a linear time trend (t) and *(unobservable × time)*$_{i,t}$ denotes district-specific effects *(DSE)*, in other words an interaction term between *unobservable* district characteristics (ν_i) and a linear time trend (t). ε_{it} is the error term. Finally, in all estimations we have controlled for spatial correlation (cross-sectional dependence) by adjusting standard errors following Hoechle (2007). This way we deal with the issue of migration and spatial spill-overs of upheaval. We control for any potential spillovers (for example 'hunger' migration across district borders) and allow this effect to decay smoothly with distance.

3.5.2 Baseline Results

Table 2 presents our main results, which indicate a robust and significant effect of weather shocks on social distress.

Table 2. *Weather Shocks* & *Social Distress*

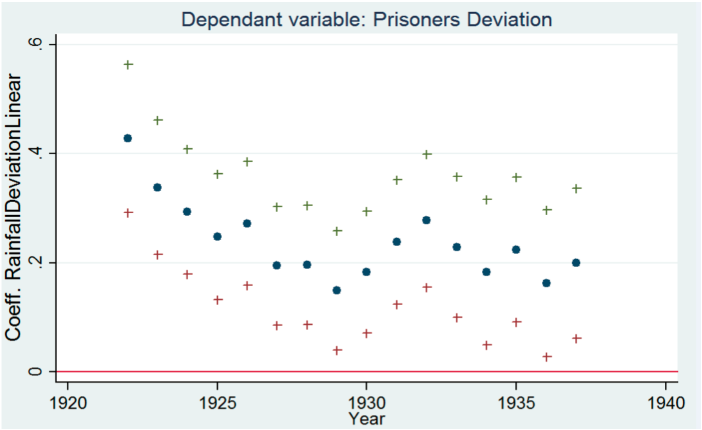
Dependent variable	(1)	(2)	(3)	(4)	(5)
Prisoners deviation	OLS	OLS	OLS	OLS	OLS
Absolute rainfall deviation	0.2919	0.2744	0.2700	0.2509	0.1698
	[8.55]***	[6.71]***	[6.66]***	[6.41]***	[3.74]***
Population density					0.0024
					[0.82]
Whites per 1000 of the population					0.0059
					[0.31]
World market prices					-0.0015
					[-0.71]
District FE	N	Y	Y	Y	Y
Time dummies	N	Y	Y	Y	Y
Observable controls × year	N	N	Y	N	N
District-specific effects (unobservable × year)	N	N	N	Y	Y
Number of observations	2335	2335	2246	2335	1665
Number of districts	143	143	137	143	104

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level. We adjust standard errors for spatial dependency following Hoechle (2007).

The absolute term of rainfall deviation yields a positive sign, and maintains a highly statistical significant coefficient, throughout our different specifications (columns 1-5). The results in column 4 indicate our preferred and most robust specification. A standard deviation increase (or decrease) in rainfall causes a 25%

increase in social distress. This result is crucial not only for its statistical significance but also for its economic significance. As shown in Figure 3, the magnitude of the effect ranges over time from 0.43 to 0.21.

Figure 3. *Rolling Coefficient of the Main Effect*



Notes: Regression coefficient in blue. Confidence level = .05 (upper bound in green, lower bound in red) time window is 5(year).

In Table 3, we include the square term of *RainfallDeviation*$_{i,t}$ and find that the effect of weather shocks on imprisonment is curvilinear (U-shaped), meaning that both drought and excessive rainfall give rise to higher levels of conviction (columns 1-5). We also test for the symmetricity of the effect by including the 'positive rainfall shock' and 'negative rainfall shock' variables into the analysis. A standard deviation *increase* in rainfall beyond the mean causes a 0.33 standard deviation increase in imprisonment. Likewise, a standard deviation *decrease* in rainfall causes a 0.25 standard deviation increase in imprisonment. A possible explanation is that in years of excessive rainfall farmers would lose their entire harvest in a relatively shorter time, whereas in years of drought farmers could hope for late rains.

Table 3. *Curvilinear Effect of Weather Shocks on Social distress*

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Prisoners deviation	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Rainfall deviation	0.0189	0.0108	0.0140	0.0139	0.0081					
	[0.93]	[0.47]	[0.66]	[0.61]	[0.29]					
Rainfall deviation squared	0.1287	0.1223	0.1179	0.1103	0.0763					
	[8.41]***	[6.34]***	[6.06]***	[6.11]***	[3.63]***					
Positive rainfall shock						0.3905	0.3354	0.3156	0.3074	0.1937
						[7.21]***	[4.98]***	[4.90]***	[4.69]***	[2.39]**
Negative rainfall shock						0.2762	0.2595	0.2516	0.2375	0.1499
						[5.11]***	[4.15]***	[4.08]***	[4.08]***	[2.23]**
Population density					0.0047					0.0045
					[1.35]					[1.31]
Whites per 1000 of the population					0.0160					0.1141
					[0.58]					[0.42]
World market prices					-0.0012					-0.012
					[-0.57]					[-0.57]
District FE	N	Y	Y	Y	N	N	Y	Y	Y	Y
Time dummies	N	Y	Y	Y	N	N	Y	Y	Y	Y
Observable controls × year	N	N	Y	N	N	N	N	Y	N	N
District-specific effects (*unobservable* × year)	N	N	N	Y	Y	N	N	N	Y	Y
Number of observations	2335	2335	2246	2335	1665	2335	2335	2246	2335	1665
Number of districts	143	143	137	143	104	143	143	137	143	104

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level. We adjust standard errors for spatial dependency following Hoechle (2007).

The impact of a rainfall shock on distress may not be immediate but only felt the next year. Table 4 presents the results when we also include lagged weather shocks as determinants of imprisonment. Column 1 shows that social distress is not associated with lags of rainfall shocks. In column 2, none of the interactions have a significant impact on imprisonment and they are jointly not statistically significant (with a p-value of 0.25). This suggests that the observed spikes in imprisonment in our data are caused by weather shocks in that particular year (leading to immediate losses in agricultural income), rather than prolonged episodes of adverse weather.

Table 4. *The Impact of Lagged Weather Conditions*

Dependent variable Prisoners deviation	(1) OLS	(2) OLS
Positive rainfall shock *t*	0.3404	0.3772
	[4.99]***	[5.25]***
Negative rainfall shock *t*	0.2422	0.2422
	[3.71]***	[3.58]***
Positive rainfall shock *t - 1*	0.0184	0.0563
	[0.36]	[1.04]
Negative rainfall shock *t - 1*	0.0700	0.0697
	[1.16]	[1.10]
Positive rainfall shock *t* × positive rainfall shock *t - 1*		-0.2407
		[-1.64]
Negative rainfall shock *t* × negative rainfall shock *t - 1*		-0.0128
		[-0.08]
District FE	Y	Y
Time dummies	Y	Y
Observable controls × year	N	N
District-specific effects (unobservable × year)	Y	Y
Number of observations	2178	2178
Number of districts	143	143

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level. We adjust standard errors for spatial dependency following Hoechle (2007).

In Table 5, we show the results after distinguishing among the different types of prisoners. As argued before, we expect short term imprisonments to be most responsive to weather shocks. This is confirmed by our estimation. The effect of weather shocks on petty crime (proxied by convictions of maximum 3 months) is almost twice as large as the effect for convictions above 3 months (columns 1-2).

Debt is also statistically significant, which suggests that weather-induced loss of incomes resulted in higher levels of debt default (column 3).

Table 5. *Results with Alternative Dependent Variables*

Dependent variable:	(1) Convictions <3 months	(2) Convictions >3 months	(3) Debt
Absolute rainfall deviation	0.2114	0.1281	0.1005
	[4.77]***	[2.99]***	[2.89]***
District FE	Y	Y	Y
Time dummies	Y	Y	Y
Observable controls × year	N	N	N
District-specific effects (unobservable × year)	Y	Y	Y
Number of observations	2250	2280	1797
Number of districts	142	144	109

Notes: OLS-FE estimator. Sample period: 1920–1939. Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level. We adjust standard errors for spatial dependency following Hoechle (2007).

3.5.3 Robustness Checks

We perform a range of robustness exercises reported in the Appendix. In Table A-1, we show that the results are largely unchanged when we replace rainfall anomalies obtained from meteorological stations with an alternative measure of rainfall obtained from the Matsuura and Wilmott (2009) world rainfall database. In Table A-2, we distinguish between *limited* drought and excess rainfall (one standard deviation from the long-term rainfall mean) and *exceptional* drought and excessive rainfall (one and a half standard deviation from the mean). The results show that the impact of *limited* drought and excessive rainfall is smaller than the impact of *exceptional* drought and excessive rainfall. The effect increases gradually as the deviation becomes larger, suggesting that the data on weather shocks make intuitive sense. In Table A-3 we include the lag of the dependent variable and run a dynamic panel data model (system-GMM). This specification gives nearly identical results. Table A-4, reports the impact of different combinations of the lags and leads. The effect remains unchanged when we control for the impact of lagged rainfall shocks at time $t - 1$ and $t - 2$. Drought and excess rainfall in the lags and leads did not have any significant impact on distress. In Table A-5, we show that the results are robust to clustering standard errors at different levels; standard errors are clustered at the year level, country level, as well as two-way clustered at both the year and the country level. Again results resemble our baseline.

3.6 Results: The Mitigating Effect of Export Crops

3.6.1 Model

To test the mitigating effect of cash crop cultivation on social distress, we estimate the following specification:

$$Y_{i,t} = \beta_1 AbsoluteRainfallDeviation_{i,t} + \pi\,(CashCropProduction \times AbsoluteRainfallDeviation)_{i,t} \\ + \delta Z'_{i,t} + v_i + \mu_t + (observable \times time)_{i,t} + (unobservable \times time)_{i,t} + \varepsilon_{i,t}. \quad (3)$$

where $(CashCropProduction \times AbsoluteRainfallDeviation)_{i,t}$ denotes the interaction of above median export crop production with *absolute rainfall deviation (linear)*. The remainder of the variables in this specification is discussed in section 5.

3.6.2 Results

The results are presented in Table 6. They strongly suggest that access to export crops mitigated the effect of weather shocks on social distress (columns 1-3). We also examine whether the effect remains unchanged when we use the *export crop suitability index* (columns 4-6). Indeed, districts where export crop suitability was high (above median) were less severely affected in years of weather shocks. The lower coefficients of our suitability indicator may reflect the fact that not all areas suitable for export crop cultivation were actually exploited in this way. These results conform with our finding that the overall treatment effect of export crops on local farmers was positive. Column 3, which is our preferred estimation, shows that export crops attenuated the effect of weather shocks on social distress by 24.5.

Table 6. *The Mitigating Effect of Export Crops*

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)
Prisoners deviation	OLS	OLS	OLS	OLS	OLS	OLS
Absolute rainfall deviation	0.3393	0.3416	0.3178	0.3173	0.3236	0.2990
	[7.21]***	[7.41]***	[7.22]***	[6.66]***	[6.93]***	[6.75]***
Export crop production × absolute rainfall deviation	-0.2376	-0.2765	-0.2456			
	[-2.80]***	[-3.26]***	[-3.02]***			
Export crop suitability × absolute rainfall deviation				-0.1507	-0.2456	-0.1709
				[-1.99]**	[-2.26]**	[-2.08]**
District FE	Y	Y	Y	Y	Y	Y
Time dummies	Y	Y	Y	Y	Y	Y
Observable controls × year	N	Y	N	N	Y	N
District-specific effects (*unobservable* × year)	N	N	Y	N	N	Y
Number of observations	2335	2246	2335	2335	2246	2335
Number of districts	143	137	143	143	137	143

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. The standard errors are clustered at the district level. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level.

3.6.3 Robustness Checks

Before making any claims about causality, one would like to know more about the relationship between export crop production and other district specific characteristics. Was the cultivation of export crops endogenously determined by an underlying variable that may also explain our results? To put it differently, was the cultivation of export crops conditional upon institutional, geographical or economic district characteristics that may also have had a *direct* mitigating effect on weather-induced vulnerability? A strong overlap between centralized political institutions and export crop production, for example, may raise a concern that such institutions explain both higher levels of export crop production, and lower vulnerability to weather shocks. In other words, our export crop indicator would capture the effect of an omitted variable. To mitigate such concerns, we provide a number of robustness tests. First, we provide a simple OLS estimation to see if the production of export crops is determined by any observable district characteristics. We proceed by estimating the following specification:

$$\textit{Cashcrop Production}_i = \text{Cashcrop Suitability}_i + \varphi V_i + \theta_i \tag{2}$$

where V_i is a vector including the different categories of district characteristics. The characteristics are divided in three categories: institutional, economic and demographic. *Institutional characteristics* include the colonial presence measured by whites per 1.000 of the population; pre-colonial centralization measured with data taken from Murdock's Ethnographic Atlas; the coercive capacity of the colonial state measured by a twenty year-average of prisoners per 1.000 of the population; and colonial investments measured by the existence of a railway (dummy). *Geographical characteristics* include controls for the length of the rainy season; degree of aridity/humidity of the climate, measured by the 20 year-average rainfall per district; the variability of rainfall using the coefficient of variation (CV) of rainfall for each district; direct access to international trade measured by a coastal dummy; and the suitability for food crops. *Economic characteristics* include alternative sources of income, including livestock measured per 1.000 of the population; rural wage labour measured by the presence of settlers (dummy); and population density as a proxy for land scarcity.

The correlations are presented in Table 7. Column 1 presents the strong correlation between export crop suitability and actual export crop production, which serves as an important validation of the empirical strategy. This practise illustrates that our measure of cash crop production and crop suitability are highly correlated at the 1% level of significance and with a coefficient greater than 0.95). For robustness, instead of taking the average of all cash crops, we only include the single most suitable cash crop per district (results do not change and are not reported). Columns 2-4 present the results from the institutional, geographical and economic controls in turn. Column 5 presents the results when we jointly include the controls. The results suggest that there are no statistically significant correlations between the district characteristics and export crop production.

Table 7. *Correlations between Export Crops and District Characteristics*

	Dependent variable Export Crop Production				
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS
Export crop suitability	0.9521	1.0677	0.9090	0.9492	1.1987
	[6.62]***	[6.67]***	[5.73]***	[6.21]***	[6.13]***
<u>Institutional controls</u>					
Colonial Presence		-0.0014			-0.0012
		[-0.44]			[-0.40]
Pre-colonial chiefdom		0.2062			0.0264
		[0.95]			[0.13]
Coercive capacity		0.0162			0.0116
		[1.57]			[1.25]
Railway dummy		0.0746			0.0773
		[0.33]			[0.31]
<u>Geographical controls</u>					
Length of rainy season			0.1287		0.1004
			[1.62]		[1.24]
Rainfall zones			-0.0001		0.0032
			[-0.02]		[0.51]
Rainfall variability CV			-1.3015		-1.7054
			[-1.34]		[-1.03]
Coastal dummy			-0.4003		-0.5392
			[-1.34]		[-1.51]
Food crop suitability			0.182		0.153
			[0.77]		[0.64]
<u>Economic controls</u>					
Livestock per 10.000 population				-0.0001	-0.0001
				[-0.47]	[-0.76]
Settler farming				-0.2650	-0.5392
				[-0.93]	[-1.70]*
Population density				-0.0002	-0.0015
				[-0.17]	[-0.93]
Number of observations	159	153	141	158	135

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. The standard errors are clustered at the district level. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level.

Additionally, we interact alternative explanations with *absolute rainfall deviation* (linear) and include this term in the regression. The most important results are presented in Table 8. Since our export crop indicator is cross-sectional, we were concerned that the mitigating effect of export crops was concentrated either at the beginning or end of our period (1920-1939). To deal with this concern, we interact *absolute rainfall deviation* (linear) with a time trend and include this term in the regression (column 1). No statistically observable trend for the mitigating impact of export crops was found.

To reaffirm that our 'export crop effect' is not driven by overall agricultural suitability, we perform a so-called 'placebo test' with food crop suitability. We split our sample into two halves (above and below median food crop suitability), and interact both absolute rainfall deviation with food crop suitability (*FoodCropSuitability × AbsoluteRainfallDeviation*) and export crop production (*ExportCropProduction × AbsoluteRainfallDeviation*). As shown in column 2, the regression results show that impact of food crop suitability on imprisonment deviation is close to 0. Hence, suitability to food crop cultivation does not explain export crop districts' greater resilience to social distress in the wake of weather shocks. This finding further enhances our confidence that the actual presence of export crops explains our heterogeneous results.

Additional 'horse race tests' are provided in Table A-6, which refute alternative institutional, geographical and income-related explanations that might (directly or indirectly) compete with export crop cultivation as an explanation for our heterogeneous results. The mitigating effect of export crops remain virtually unchanged. Finally, we also check the robustness of our estimates to the use of alternative samples. A first concern is the possibility that higher spikes of imprisonment in our below-median export crop sample is not driven by the absence of export crops, but by the presence of settlers (all settler districts end up in the below-median export crop sample).

A potential concern is that land alienation and extractive institutions could potentially have an aggravating effect on social distress. We thus exclude the settler districts from the analysis (column 3) and find that our results remain robust. A second issue is that the mitigating effect of export crops is driven by districts with cocoa, which are sometimes portrayed as an exceptional case of successful export crop adoption. To rule out the possibility that our export crop interaction effect is driven by cocoa, we created a sub-sample excluding the cocoa districts from the analysis, and find that our results remain robust (column 4).

Table 8. *Robustness Checks: Trends, Food Crops and Sub-Samples*

Dependent variable	(1)	(2)	(3)	(4)
Prisoners deviation	OLS	OLS	OLS	OLS
Absolute rainfall deviation	0.4270	0.3158	0.3613	0.3179
	[5.22]***	[7.12]***	[7.57]***	[6.77]***
Export crop production × absolute rainfall deviation	-0.2355	-0.2445	-0.2290	-0.2482
	[-2.94]***	[-3.01]***	[-2.57]***	[-3.00]***
Absolute rainfall deviation × trend	-0.0103			
	[-1.52]			
Food crop suitability × absolute rainfall deviation		0.0475		
		[0.21]		
District FE	Y	Y	Y	Y
Time dummies	Y	Y	Y	Y
Observable controls × year	N	N	N	N
District-specific effects (*unobservable* × year)	Y	Y	Y	Y
Number of observations	2335	2335	1909	2199
Number of districts	143	143	117	135

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. The standard errors are clustered at the district level. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent.

3.7 Conclusion

This study has investigated two key questions. First, to what extent did weather shocks induce higher levels of social distress in colonial British Africa? Second, to what extent did the cultivation of export crops mitigate weather-induced distress? Building on newly collected data, it provides two contributions. First, our analysis indicates that both annual drought and excessive rainfall caused spikes in imprisonment. On the basis of previous literature, together with our reading of the colonial administrative records, we conclude that depressed agricultural incomes is the key pathway linking exogenous rainfall shocks to spiking imprisonment rates. Second, we find that the production of export crops had a *mitigating* effect on weather-induced distress. In the context of interwar British colonial Africa, districts with more export crops displayed less pronounced spikes of imprisonment in years of weather shocks, than those districts with few or none at all. The results indicate that the presence of export crops drives our heterogeneous results, which hold up to a battery of performed robustness tests, which effectively refute a wide range of plausible alternative explanations.

Our findings are set in the historical context of interwar British colonial Africa. However, many African smallholders today still face agricultural and climatological conditions resembling those found in this historical setting. We posit therefore, that our highly significant and robust findings on the effects of weather fluctuations, and the mitigating effects of agricultural commercialization, bear great relevance for today's vulnerable rural societies, particularly now with the increase in severe and frequent weather extremes generated by accelerated climate change.

That *even in a colonial context*, smallholder-based export crop cultivation was seen to have a mitigating effect on weather-induced distress, suggests that providing smallholders with the ability to produce for external markets should be a key policy priority. At the same time it would be unwarranted, even reckless, to claim that 'state sponsored' export crops are a 'magic bullet', or even that agricultural commercialization more generally is universally beneficial to mitigating rural societies' vulnerability to weather shocks. When interpreting our findings, it is particularly important to recognise the fact that most of colonial tropical Africa was *land abundant*, that smallholders combined cultivation of export and subsistence crops, and that while inputs were low and farming techniques basic, smallholders generally did not have to incur debts to participate in cultivation for export. Moreover, in districts which were not suitable for the cultivation of export crops, their introduction would not be a viable strategy to mitigate vulnerability.

Our empirical strategy allowed us to tease out a robust *overall treatment effect* of export crops on weather-induced distress at district-level. The scope of our analysis and the scarcity of reliable data prevented an analysis of the complex, variegated set of mechanisms through which agricultural commercialization mitigates vulnerability to weather shocks. Our findings should, therefore, be interpreted in the light of the existing rich case-study literature, in which such mechanisms are exposed in much greater detail. Three complementary sets of mechanisms require particular consideration.

Firstly, how does export crop cultivation affect agricultural incomes in years of abnormal weather? The cultivation of (mostly non-edible) export crops may lead households to forego the cultivation of surplus subsistence crops having potential to serve as a buffer in case of bad harvest. Such bad harvest would be faced by all district farmers, resulting in overall lack of food, which may readily transfer into distress. The food-export crop substitution effect may be aggravated by the fact that export crops such as cotton or tobacco are highly labor intensive. Why, then, do we find a positive effect? It is possible that the introduction of new, exportable crops may reduce the risk of *complete* harvest failure. Weather conditions may impact export crops and local food crops differently (Maxwell & Fernando 1989; Morton, 2007). Moreover, 'state sponsored' export crops tend to include extension services, agricultural innovations and new inputs, all or any of which may benefit the climate-resilience of agriculture (Goetz, 1993). Despite few high-yielding food crop varieties being brought to smallholders in colonial Africa, the adoption of export crops did coincide with a partial switch to less labour-intensive and more drought-resistant food crops, such as cassava which, although less nutritious, may have enhanced food security (Tosh, 1980).

Secondly, how do export crops affect the ability of *households* to overcome distress in years of depressed agricultural incomes? If the cultivation of export crops provokes food shortages in bad years, it may still enhance smallholders' abilities to overcome such shortages through forward planning. Production for market enables households to convert (a part of) their harvest into storable wealth (such as cash or livestock), which enables the purchase of food in bad years. This 'consumption smoothing' is conditional upon smallholders actually receiving the income benefits from export cultivation, which is not self-evident. Structural indebtedness or excessive taxation may negatively impact storable wealth, preventing smallholders from utilizing their export crop income to alleviate distress (Bates, 1981; Scott, 1976). However, the positive treatment effect suggests that export crop growers enjoyed increased purchasing power, despite colonial conditions. While the colonial tax burden on smallholder export crops was indeed excessive, it was not high enough to completely annul the gains in purchasing power arising from export crop cultivation (De Haas, 2016).

Thirdly, how do export crops affect the ability of *communities* to overcome distress in years of depressed agricultural incomes? The adoption of export crops does not only have repercussions on the level of the individual smallholder, but also on the broader institutional and infrastructural context. While scholars have argued that rural commercialization erodes pre-capitalist, 'moral economy' insurance institutions (Fafchamps, 1992; Scott, 1976; Watts, 1983), the revenue-generating potential of export crop regions may also provide the state with the means to invest in technology diffusion, infrastructure and food security (Govereh & Jayne, 2003). Some of our overall positive treatment effect may be explained by such investments.

We find it plausible that each of the three channels described above contributes to explain our findings, whilst reiterating that colonial occupation may – through excessive taxation, insufficient commitment to rural development or insistence on a limited set of 'state sponsored' export crops – have prevented smallholders from realizing maximum available benefit from agricultural commercialization. Further disentangling the mechanisms suggested above should continue to be a top priority for scholars and policy makers.

We suggest a number of directions for future research. Firstly, in relation to the discussion above, it would be of particular interest to see if the effect of export crops is primarily channelled through higher *private income* or through *public investments* in infrastructure and food aid programs. Secondly, further study may uncover different results for aspects of distress not touched upon in this paper, such as malnutrition or uneven vulnerabilities across class and gender. Thirdly, it would be valuable to give focused attention to the actual adoption of different types of export crops and identify conditions determining successful adoption. Our finding that export crop suitability mattered for the adoption of export crops, implies that areas unsuitable for such traditional export crops require different agricultural commercialization strategies, perhaps based on suitable, drought-resistant food crops such as cassava or sorghum, or even alternative, non-agricultural 'roads to openness'. Fourthly, while this study finds a *short term* mitigating effect of export crops on distress, it does not address the *long-term* effects; which may include the risk of a 'commodity trap' or the adverse environmental impacts of agricultural commercialization. Thus, a more complete understanding of the impact of export crops would require further empirical study into the *long-run effects* of these crops.

Appendix A. Robustness Tests

Table A-1. *Main Results with Absolute Rainfall Deviation, Grids*

Dependent variable	(1)	(2)	(3)	(4)	(5)
Prisoners deviation	OLS	OLS	OLS	OLS	OLS
Absolute rainfall deviation (Grids)	0.1632	0.1794	0.1636	0.1689	0.1667
	[4.95]***	[4.89]***	[4.63]***	[5.07]***	[3.85]***
Population density					0.0045
					[1.35]
Whites per 1000 of the population					0.0117
					[0.45]
World market prices					-0.0010
					[-0.52]
District FE	N	Y	Y	Y	Y
Time dummies	N	Y	Y	Y	Y
Observable controls × year	N	N	Y	N	N
District-specific effects (unobservable × year)	N	N	N	Y	Y
Number of observations	2680	2680	2422	2680	1827
Number of districts	156	156	137	156	105

Notes: Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level.

Table A-2. *The Impact of Droughts and Excessive rainfall on Social Distress*

Dependent variable:	Prisoners deviation			
	(1)	(2)	(3)	(4)
Exceptional positive rainfall shock	0.3256	0.3566	0.3627	0.3540
	[3.38]***	[3.79]***	[3.84]***	[3.69]***
Exceptional negative rainfall shock	0.3259	0.2955	0.2461	0.2204
	[3.32]***	[2.78]***	[2.37]**	[2.26]**
Limited positive rainfall shock	0.2523	0.1799	0.1573	0.1558
	[3.73]***	[2.36]**	[2.12]**	[2.07]**
Limited negative rainfall shock	0.1522	0.1448	0.1585	0.1540
	[2.32]**	[2.06]**	[2.38]**	[2.55]**
District FE	N	Y	Y	Y
Time dummies	N	Y	Y	Y
Observable controls × year	N	N	Y	N
District-specific effects (unobservable × year)	N	N	N	Y
Number of observations	2335	2335	2246	2335
Number of districts	143	143	137	143

Notes: OLS estimator. Sample period: 1920–1939. Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level.

Table A-3. *The impact of Lagged Imprisonment and Absolute Rainfall Deviation*

Dependent variable	(1)	(2)	(3)
Prisoners deviation	GMM	GMM	GMM
Prisoners deviation, lagged *t - 1*	0.4273	0.6906	
	[10.71]***	[14.99]***	
Absolute rainfall deviation	0.1926	0.2361	0.2073
	[4.15]***	[2.79]***	[3.29]***
Absolute rainfall deviation, *t - 1*			-0.0089
			[-0.04]
Absolute rainfall deviation, *t - 2*			0.0472
			[0.92]
District FE	Y	Y	Y
Time dummies	Y	Y	Y
Observable controls × year	N	N	N
District-specific effects (unobservable × year)	N	Y	Y
Number of observations	2216	2216	1995
Number of districts	143	137	143
Number of instruments	169	309	168
AR1 statistics (p-value)	0.000	0.000	0.000
AR2 statistics (p-value)	0.216	0.638	0.220
Hansen test (p-value)	0.987	0.942	0.299

Notes: System-GMM estimation for dynamic panel data-model. Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Second (and latter) lags were used as instruments in the first-differenced equations, and their once-lagged first differences were used in the levels equation. Two-step results using robust standard errors corrected for finite samples using correction. We adjust standard errors for spatial dependency following Conley (1999).

Table A-4. *The Impact of Droughts & Excessive rainfall on Social Distress*

	Dependent variable: Prisoners deviation				
	(1)	(2)	(3)	(4)	(5)
Positive rainfall shock $t + 2$	-0.0062 [-0.12]				
Negative rainfall shock $t + 2$	0.0587 [-1.16]				
Positive rainfall shock $t + 1$		0.0834 [1.63]			
Negative rainfall shock $t + 1$		0.0170 [0.33]			
Positive rainfall shock t			0.3354 [4.98]***		
Negative rainfall shock t			0.2595 [4.15]***		
Positive rainfall shock $t - 1$				-0.0006 [-0.01]	
Negative rainfall shock $t - 1$				0.0560 [0.95]	
Positive rainfall shock t - 2					-0.0210 [-0.37]
Negative rainfall shock t - 2					0.0412 [0.72]
District FE	Y	Y	Y	Y	Y
Time dummies	Y	Y	Y	Y	Y
Observable controls × year	N	N	N	N	N
District-specific effects (unobservable × year)	Y	Y	Y	Y	Y
Number of observations	2166	2286	2335	2211	2077
Number of districts	143	143	143	143	143

Notes: OLS estimator. Sample period: 1920–1939. Corrected t-statistics are shown in brackets. Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Standard errors are clustered at the district level. Column (3) replicates the results in column 7 of Table 3.

Table A-5. *Clustering Standard Errors at Different Levels*

	Dependent variable: Prisoners deviation			
	(1) OLS	(2) OLS	(3) OLS	(4) OLS
Rainfall Deviation Stations	0.2919	0.2744	0.2700	0.2509
	(0.0437)	(0.0408)	(0.0405)	(0.0391)
		<0.0930>	<0.0854>	<0.0834>
		[0.0905]	[0.0825]	[0.0759]
Rainfall Deviation Grids	0.1632	0.1739	0.1636	0.1695
	(0.0371)	(0.0355)	(0.0353)	(0.0336)
		<0.0865>	<0.0752>	<0.0725>
		[0.0793]	[0.0716]	[0.0667]
District FE	N	Y	Y	Y
Time dummies	N	Y	Y	Y
Observable controls x year	N	N	Y	N
District-specific effects (unobservable x year)	N	N	N	Y
Number of observations	2335	2680	2422	2680

Notes. The specifications and the estimated coefficients in this table are the same as in Table 2 and Table A-1. The standard errors in columns 2–4 are clustered at the district level (in parentheses), the country level (in angle brackets) as well as two-way clustered both the country and the year level (in square brackets).

Appendix B. Cash crop production calculation

We proceed in the following steps:

(i) We obtain *annual, crop-specific, country-level cash crop export values*, compiled in the Wageningen African Trade Database, for the years 1920 to 1939;

(ii) We collect *annual, crop-specific, district-level, smallholder cash crop production estimates* for the years 1920 to 1939. We use a range of sources, including colonial maps, annual statistics and agricultural censuses. We inter-/extrapolate if production data is not available for all years. The data is rough but suffices to estimate the shares of different districts in total country production.

(iii) We use (ii) to distribute (i) over the individual districts, for each of the countries in our dataset.

(iv) We add up the value of all cash crops grown in a district to arrive at an indicator of *annual, district-level cash crop export values per district.*

(v) We divide (iv) over *annual, district-level population figures* to arrive at an indicator of *annual, district-level, smallholder cash crop export value per capita*. We inter-/extrapolate if population data is not available for all years.

(vi) We take the average of (v) for the years 1920-1939 to arrive our indicator of *cash crop intensity (average annual value of cash crops in pounds per capita).*

A simple example is given below. We have followed a similar procedure for all the districts in our dataset.

(i) The total value of Nyasaland's cotton production in the years 1920-1939, following the Wageningen African Trade Database, fluctuated between a minimum of £35 thousand in 1932 and a maximum of £205 thousand in 1935.

(ii) The colonial Bluebooks of Nyasaland report annual estimates of district-level native cotton production. The *Lower Shire District*'s contribution, according to these estimates, fluctuated between 21 and 65 per cent of the country's total cotton production between 1920 and 1939.

(iii) By multiplying the annual value (i) with the Lower Shire's production share (ii), we find that the value of cotton produced in the Lower Shire district fluctuated between a minimum of £14 thousand and a maximum of £67 thousand.

(iv) The Lower Shire District only produces cotton so we can use the cotton figures, without having to add up values of different cash crops.

(v) We deflate these annual district-level values with district-level population numbers to obtain an estimate of *gross-export-crop-income per capita*, which in the case of the Lower Shire varies between £0.2 (during the depression years), and £0.8 per capita.

(vi) Because both the district-level production estimates and population figures can only be considered rough proxies of reality, we discard annual fluctuations and take the average of the entire 20-year period as our indicator for cash crop intensity. The average gross annual per capital export income for the Lower Shire district is £0.4.

<u>Gold Coast</u>

District borders are the administrative borders from 1930 reported in Gold Coast 'Administration Report 1930'. District-level, smallholder production shares for cocoa, cola nuts, copra and palm oil are estimated using maps in Cardinall

(1932) and Kaplan et al. (1971). No panel data on cash crop production is used. The 1931 map-based production shares are used for the entire period (1920-1939). District-level, cash crop production shares are obtained by dividing the district's production estimates by the country-sum of production estimates. Annual, district-level smallholder cash crop production values are obtained by multiplying the 1931 production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Gold Coast Blue Books (1920-1939). For some districts, only data for 1930 is available. Missing years are extrapolated using a nearby district. Note that the maps only indicate the area in which cash crops were produced, and do not indicate the intensity of production or yields. Hence, the assigned shares are a rough approximation of reality.

Nigeria

District level data for Nigeria is not available. Instead, we use provinces. Borders are obtained from Papaioannou (2016a). Province-level, smallholder production shares for cocoa, cotton, groundnuts and palm oil are estimated using maps cited in Papaioannou 'Climate shocks and conflict'. No panel data on cash crop production is used. The map-based production shares are used for the entire period (1920-1939). District-level, cash crop production shares are obtained by dividing the district's production estimates by the country-sum of production estimates. Annual, district-level smallholder cash crop production values are obtained by multiplying the map-based production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Nigeria Blue Books (1920-1939). Note that the maps only indicate the area in which cash crops were produced, and do not indicate the intensity of production or yields. Hence, the assigned shares are a rough approximation of reality.

Sierra Leone

District borders are administrative borders from 1920-30, reported in Abraham (1978). District-level, smallholder production shares for ginger and palm oil are estimated using production estimates for 1938, reported on a map in Sierra Leone 'Administration Reports'. No panel data on cash crop production is used. The 1938 production shares are used for the entire period (1920-1939). District-level, cash crop production shares are obtained by dividing the district's production estimates by the country-sum of production estimates. Annual, district-level smallholder cash crop production values are obtained by multiplying the 1938 production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Sierra Leone Blue Books (1920-1939). Note that the districts in Sierra Leone shifted somewhat between the interwar period and today. The graphical representation on the map, hence, is not fully accurate.

Gambia

Gambia is treated as one district. Cash crop production (groundnuts) in that district can be equated to the total annual export figure in the WTD. Population figures from Gambia Blue Books (1920-1939). Note that considerable numbers of migrants ('strange farmers') came annually to the Gambia to produce groundnuts. Since these migrants are not counted in the population figures, the cash crop intensity may be biased slightly upwards.

Tanganyika

District borders are the administrative borders from 1933 reported in Berry (1972). District-level, smallholder production estimates for coffee, copra, cotton, groundnuts, sesame and tobacco are obtained from the Tanganyika Blue Books (1926, 1927, 1929, 1930, 1932, 1933, 1935, 1937, 1938 and 1939). District-level, cash crop production shares are obtained by dividing the district's production estimates by the country-sum of production estimates. As the country export data does not distinguish between smallholder- and expatriate-produced cash crops,

crops (coffee) produced by expatriate farmers are included into this country sum. Production shares for missing years are interpolated. The shares for 1920-1925 are set equal to the average share of 1926 and 1927. Annual, district-level smallholder cash crop production values are obtained by multiplying the annual production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Tanganyika Blue Books (1928, 1931, 1939). Missing years are inter-/extrapolated using the same procedure as for the production estimates. Note that some of the crops included (copra, groundnuts and sesame) were both consumed locally and exported. We are forced to assume that exports are equally divided over the producing districts, but this assumption has only a minor effect on the eventual cash crop intensity estimates.

Zanzibar

District borders coincide with Pemba Island and Zanzibar Island. District-level, smallholder production estimates for cloves and copra are obtained by estimating the relative contribution of the two Islands based on production figures in Zanzibar 'Administration Reports'. District-level, cash crop production shares are obtained by dividing the district's production estimates by the country-sum of production estimates. As the country export data does not distinguish between smallholder- and expatriate-produced cash crops, we roughly estimate expatriate-plantation clove production at 50% and copra production at 20% and include the crops produced by expatriate farmers into the country sum. Annual, district-level smallholder cash crop production values are obtained by multiplying the annual production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Zanzibar Blue Books (1920-1939).

Kenya

District borders are from Kenya 'Administration Reports 1931'. District-level, smallholder production estimates for cotton, wattle, sesame, groundnuts and coconuts are obtained from Kenya ‘Agricultural Census 1930’. No panel data on cash crop production is used. The 1930 production shares are used for the entire period (1920-1939). District-level, cash crop production shares are obtained by dividing the district’s production estimates by the country-sum of production estimates. As the WTD does not distinguish between smallholder- and expatriate-produced cash crops, crops (maize and wattle) the total reported value of smallholder produced crops is taken as a share of total production, including production at expatriate farms. This share is applied to the entire period. Annual, district-level smallholder cash crop production values are obtained by multiplying the 1930 production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Kenya Colony Blue Books (1927, 1929, 1934, 1938). Missing years are inter-/extrapolated using a procedure analogous to the production estimates under ‘Tanganyika’. Note that the district-level production figures are based on sales rather than production. Note that some of the crops included (maize, sesame, groundnuts, coconuts) were both consumed locally and exported. We are forced to assume that exports are equally divided over the producing districts, but this assumption has only a minor effect on the eventual cash crop intensity estimates.

Uganda

District borders are from Uganda ‘Administration Reports 1948’, with some modifications based on Wrigley (1959). District-level, smallholder production estimates for coffee and cotton are obtained from the Uganda Blue Books (1920, 1923, 1926, 1929, 1932, 1935 and 1938). District-level, cash crop production shares are obtained by dividing the district’s production estimates by the country-sum of production estimates. As the country export data does not distinguish between smallholder- and expatriate-produced cash crops, crops (coffee) produced by expatriate farmers are included into this country sum. Production shares for missing years are set equal to the closest available year. Annual, district-level smallholder cash crop production values are obtained by multiplying the annual production shares with annual country-level, crop-specific exports from the Uganda Bluebooks (the WTD does not break down export data for Kenya and Uganda). All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Uganda Blue Books (1920, 1923, 1926, 1929, 1932, 1935 and 1938). Missing years are inter-/extrapolated using the same procedure as for the production estimates. Note that the district shares, as well as the smallholder versus expatriate shares are based on acreage rather than production, meaning that yield differences between provinces is not taken into account. This may slightly diminish the accuracy of the cash crop intensity estimates.

Nyasaland

District borders are from Nyasaland 'Administration Reports 1933'. District-level, smallholder production estimates for cotton and tobacco are obtained from the Nyasaland Blue Books (1923, 1925, 1927, 1929, 1931, 1933, 1935, 1937 and 1939). District-level, cash crop production shares are obtained by dividing the district's production estimates by the country-sum of production estimates. As the country export data does not distinguish between smallholder- and expatriate-produced cash crops, crops (both cotton and tobacco) produced by expatriate farmers are included into this country-sum. Production shares for missing years are inter-/extrapolated (analogous to procedure described under 'Tanganyika' above). Annual, district-level smallholder cash crop production values are obtained by multiplying the annual production shares with annual country-level, crop-specific exports from the WTD. All crops are added up and the resulting total is divided by the district population. Annual population figures are obtained from Nyasaland Blue Books (1920-1938). Missing years are inter-/extrapolated using the same procedure as for the production estimates. Note that the district-level production figures are based on sales rather than production. The Blue Books explicitly note that this way of measuring diminishes the accuracy of production estimates, as 'many natives grow their tobacco and cotton in one district and sell in another'.

Bechuanaland

Districts borders based on a map kindly provided by Ellen Hillbom. No smallholder cash crops were exported from Bechuanaland. All districts are set at 0.

Northern Rhodesia

No map from the interwar period was available. Instead we used district borders based Northern Rhodesia 'Administration Reports 1948'. No smallholder cash crops were exported from Northern Rhodesia. All districts are set at 0.

General notes

Population figures are obtained from the Blue Books. These official population figures are generally considered to be much too low (see Frankema & Jerven, (2014). However, we are still very far from revising these official colonial population figures on the district level. Hence, we consistently use the colonial figures, taking stock of the possibility that our per capita estimates are too high all across the board and that some inaccuracy may enter the dataset as some districts may have been more accurately counted than others.

Country-level exports of each of the crops are obtained from Wageningen Trade Database (WTD). These figures are generally considered highly accurate and hence serve as the basis of our estimates. However, we do not account for the possibility that a share of the export value did not accrue to others in the production chain.

Historical Sources

Statistical yearbooks and administration reports were used for the following colonies (various issues): the Tanganyika Territory, Nyasaland Protectorate, the Colony and Protectorate of Nigeria, the Gold Coast Colony, the Colony of the Gambia, Kenya Colony, Sierra Leone, the Protectorate of Northern Rhodesia and Bechuanaland.

References

Abraham, A. (1978). *Mende government and politics under colonial rule : a historical study of political change in Sierra Leone, 1890-1937*. Freetown, Sierra Leone; Oxford: Sierra Leone University Press ; Distributed by Oxford University Press.

Adano, W. R., Dietz, T., Witsenburg, K., & Zaal, F. (2012). 'Climate change, violent conflict and local institutions in Kenya's drylands'. *Journal of Peace Research*, 49(1): 65-80.

Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in human geography*, 24

Ahmed, S. A., Diffenbaugh, N. S., & Hertel, T. W. (2009). Climate volatility deepens poverty vulnerability in developing countries. *Environmental Research Letters*, 4(3), 034004.

Almer, C., & Boes, S. (2012). "Climate (change) and conflict: Resolving a puzzle of association and causation, " Discussion Papers, Department of Economics, University of Bern.

Amin, S. (1972). Underdevelopment and dependence in Black Africa—origins and contemporary forms. *The Journal of Modern African Studies*, *10*(04), 503-524.

Austin, G. (2008). Resources, techniques, and strategies south of the Sahara: revising the factor endowments perspective on African economic development, 1500–20001. *The Economic History Review*, *61*(3), 587-624.

Austin, G. (2014a). Vent for surplus or productivity breakthrough? The Ghanaian cocoa take-off, c. 1890–1936. *The Economic History Review*, *67*(4), 1035-1064.

Austin, G. (2014b). Explaining and evaluating the cash crop revolution in the" peasant" colonies of tropical Africa, ca. 1890-ca. 1930: beyond" vent for surplus. *E. Akyeampong, RH Bates, N. Nunn, & J. Robinson, A.(Eds.), Africa's development in historical perspective*, 295-320.

Auffhammer, M., Hsiang, S. M., Schlenker, W., & Sobel, A. (2013). Using weather data and climate model output in economic analyses of climate change. *Review of Environmental Economics and Policy*, ret016.

Barrios, S, Bertinelli, L., & Strobl E. (2010). "Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the Growth Tragedy," *The Review of Economics and Statistics*, 92(2): 350-366.

Bates, R. H. (1981). *Markets and states in tropical Africa: the political basis of agricultural policies*. Berkeley, CA: University of California Press.

Benjaminsen, T. A., Alinon, K., Buhaug, H., & Buseth, J. T. (2012). 'Does climate change drive land-use conflicts in the Sahel?'. *Journal of Peace Research*, 49(1): 97-111.

Bernault, F. (2007). The Shadow of Rule: Colonial Power and Modern Punishment in Africa. *Cultures of Confinement: A History of the Prison in Africa, Asia and Latin America*, 55-94.

Berry, L. (1972). *Tanzania in maps: graphic perspectives of a developing country*. New York, Africana Pub. Corp

Binswanger, H. P., & McIntire, J. (1987). Behavioral and Material Determinants of Production Relations in Land-Abundant Tropical Agriculture. *Economic Development and Cultural Change, 36*(1),73-99

Blakeslee, D. S., & Fishman, R. (2015). Weather shocks, crime, and agriculture: evidence from India. *Social Science Research Network*.

Blattman, C., & Miguel, E. (2010). "Civil war," *Journal of Economic Literature*, 3-57.

Bowden, S., Chiripanhura, B., & Mosley, P. (2008). Measuring and explaining poverty in six African countries: A long-period approach. *Journal of International Development*, *20*(8), 1049-1079.

Branch, D. (2005). Imprisonment and Colonialism in Kenya, c.1930-1952: Escaping the Carceral Archipelago. *The International Journal of African Historical Studies*, 38(2), 239-265

Brückner, M., & Ciccone, A. (2011). 'Rain and the democratic window of opportunity'. Econometrica, 79(3): 923-947.

Bryceson, D. (1981). Colonial famine responses: the Bagamoyo district of Tanganyika 1920-1961. *Food Policy*(May), 91-104.

Bryceson, D. (1988). Peasant cash cropping versus self-sufficiency in Tanzania: a historical perspective. *IDS Bulletin, 192*, 37-46.

Bryceson, D. F. (2002). The scramble in Africa: reorienting rural livelihoods. *World development*, *30*(5), 725-739.

Buhaug, H. (2010). Climate not to blame for African civil wars. *Proceedings of the National Academy of Sciences, 107*(38), 16477-16482.

Buhaug, H., Nordkvelle, J., Bernauer, T., Böhmelt, T., Brzoska, M., Busby, J. W., ... & Goldstone, J. A. (2014). One effect to rule them all? A comment on climate and conflict. *Climatic Change*, *127*(3-4), 391-397.

Burgess, R., & Donaldson, D. (2010). Can openness mitigate the effects of weather shocks? Evidence from India's famine era. *The American Economic Review*, 449-453.

Burke, M., Dykema, J., Lobell, D. B., Miguel, E., & Satyanath, S. (2015). Incorporating climate uncertainty into estimates of climate change impacts. *Review of Economics and Statistics*, *97*(2), 461-471.

Cardinall, A. W. (1932). *The Gold Coast, 1931 : a review of conditions in the Gold Coast in 1931 as compared with those of 1921, based on figures and facts collected by the chief census officer of 1931, together with a historical, ethnographical, and sociological survey of the people of that country*. Accra, Government Printer.

Carswell, G. (2003). Food crops as cash crops: the case of colonial Kigezi, Uganda. *Journal of Agrarian Change*, *3*(4), 521-551.

Chambers, R., & Conway, G. (1992). *Sustainable rural livelihoods: practical concepts for the 21st century*. Institute of Development Studies (UK).

Collier, P., & Dercon, S. (2014). African Agriculture in 50Years: Smallholders in a Rapidly Changing World?. *World development*, *63*, 92-101.

Couttenier, M., & Soubeyran, R. (2011). Drought and civil war in Sub-Saharan Africa. *FEEM Working Paper No. 150*.

Christian, C., & Fenske, J. (2015). Economic shocks and unrest in French West Africa. *CSAE Working Paper WPS/2015-01*.

De Janvry, A., Fafchamps, M., & Sadoulet, E. (1991). Peasant household behavior with missing markets: Some paradoxes explained. *Economic Journal, 101*(409), 1400-1417.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature*, *52*(3), 740-798.

Deschenes, O. (2014). Temperature, human health, and adaptation: A review of the empirical literature. *Energy Economics*, 46, 606-619.

Ellis, F. (1993). *Peasant economics: farm households in agrarian development*. Cambridge: Cambridge University Press.

Ember, C. R., Adem, T. A., Skoggard, I., & Jones, E. C. (2012). Livestock raiding and rainfall variability in Northwestern Kenya. *Civil Wars, 14*(2), 159-181.

Fafchamps, M. (1992). Cash Crop Production, Food Price Volatility, and Rural Market Integration in the Third World. *American Journal of Agricultural Economics*, 74(1), 90-99.

Fenske, J., & Kala, N. (2015). Climate and the slave trade. *Journal of Development Economics*, *112*, 19-32.

Fjelde, H., & von Uexkull, N. (2012). 'Climate triggers: Rainfall anomalies, vulnerability and communal conflict in sub-Saharan Africa'. *Political Geography*, 31(7): 444-453.

Folke, C. (2006). Resilience: the emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3), 253-267.

Frankema, E., Williamson, J., & Woltjer, P. (2015). *An economic rationale for the African scramble: the commercial transition and the commodity price boom of 1845-1885* (No. w21213). National Bureau of Economic Research.

Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global environmental change*, 16(3), 293-303

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: the heretics' view. *Field crops research*, *114*(1), 23-34.

Govereh, J., & Jayne, T. S. (2003). Cash cropping and food crop productivity: synergies or trade-offs?. *Agricultural economics*, *28*(1), 39-50.

Gray, J. P. (1999). A corrected ethnographic atlas. *World Cultures*, 10(1), 24-85.

Harari, M., & La Ferrara, E. (2013). Conflict, Climate and Cells: A disaggregated analysis.

Hendrix, C. S., & Salehyan, I. (2012). Climate change, rainfall, and social conflict in Africa. *Journal of Peace Research, 49*(1), 35-50. doi: 10.1177/0022343311426165

Hill, P. (1982). Dry Grain Farming Families: Hausaland (Nigeria) and Karnataka (India) Compared: Cambridge University Press.

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. Stata

Hogendorn, J. S. (1978). *Nigerian groundnut exports*. Ahmadu Bello University Press.

Homer-Dixon, T. F. (1999). *Environment, scarcity and violence*. Princeton: Princeton University Press.

Hsiang, S. M., Burke, M., & Miguel, E. (2013). 'Quantifying the influence of climate on human conflict'. Science, 341(6151): 53-67.

Hsiang, S. M. (2016). *Climate Econometrics* (No. w22181). National Bureau of Economic Research.

Hughes, C. C., & Hunter, J. M. (1970). Disease and "development" in Africa. *Social Science & Medicine*.

Hynd, S. (2008). Killing the Condemned: the Practice and Process of Capital Punishment in British Africa, 1900-1950s. *The Journal of African History, 49*(03), 403-418

Isaacman, A. (1980). *"Cotton is the mother of poverty": peasant resistance to forced cotton production in Mozambique, 1938-1961*. London: James Currey.

Iyer, L., & Topalova, P. B. (2014). Poverty and crime: evidence from rainfall and trade shocks in India. *Harvard Business School BGIE Unit Working Paper*, (14-067).

Jayne, T. S., Govereh, J., Wanzala, M., & Demeke, M. (2003). Fertilizer market development: a comparative analysis of Ethiopia, Kenya, and Zambia. *Food Policy*, *28*(4), 293-316.

Jia. R. (2014). "Weather shocks, sweet potatoes and peasant revolts in historical China", *The Economic Journal, 124*(575), 92-118.

Kahl, C. H. (2006). States, scarcity, and civil strife in the developing world. Princeton: Princeton University Press.

Kaplan, I. (ed.) (1971). *Area handbook of Ghana.* Washington, D.C., U.S. Government Printing Office.

Killingray, D. (1986). The Maintenance of Law and Order in British Colonial Africa. *African Affairs, 85*(340), 411-437

Klomp, J., & Bulte, E. (2013). 'Climate change, weather shocks, and violent conflict: a critical look at the evidence'. *Agricultural Economics,* 44(s1): 63-78.

Likaka, O. (1997). *Rural Society and Cotton in Colonial Zaire*. University of Wisconsin Press.

MacKenzie, A. F. D. (1999). Betterment and the gendered politics of maize production, Murang'a district, Central Province, Kenya, 1880-1952. *Canadian Journal of African Studies*, 33(1), 64-97.

Mandala, E. C. (1990). Work and Control in a Peasant Economy: a history of the lower Tchiri valley in Malawi, 1859-1960.

Matsuura, K. & Willmott, C. J. (2009). *Terrestrial precipitation: 1900–2008 gridded monthly time series.* Centre for Climatic Research Department of Geography, Centre for Climatic Research, University of Delaware.

Maxwell, S., & Fernando, A. (1989). Cash crops in developing countries: The issues, the facts, the policies. *World Development*, 17(11), 1677-1708

Maystadt, J. F., & Ecker, O. (2014). Extreme weather and civil war: does drought fuel conflict in Somalia through livestock price shocks?. *American Journal of Agricultural Economics*, 96(4), 1157-1182.

Miguel, E., Satyanath, S., & Sergenti, E. (2004). 'Economic shocks and civil conflict: An instrumental variables approach'. *Journal of Political Economy*, 112(4): 725-753.

Moradi, A., & Baten, J. (2005). Inequality in Sub-Saharan Africa: new data and new insights from anthropometric estimates. *World development*, *33*(8), 1233-1265.

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the national academy of sciences*, *104*(50), 19680-19685.

Mosley, P. (1980). *The settler economies: studies in the economic history of Kenya and Southern Rhodesia 1900-1963* (Doctoral dissertation, University of Cambridge).

Murdock, G. P. (1967). *Ethnographic atlas*. Pittsburgh: University of Pittsburgh Press.

Myint, H. (1958). The classical theory of international trade and the underdeveloped countries. *Economic Journal, 68*, 317-337.

Nunn, N., & Qian, N. (2010). The Columbian exchange: A history of disease, food, and ideas. *The Journal of Economic Perspectives*, *24*(2), 163-188.

Papaioannou, K. J. (2016a). 'Climate Shocks and Conflict: Evidence from colonial Nigeria'. *Political Geography*, 50(1): 33-47

Papaioannou, K. J. (2016b). 'Hunger Makes a Thief of Any Man': Poverty and Crime in British Colonial Asia. *European Review of Economic History*.

Raikes, P., & Gibbon, P. (2000). 'Globalisation' and African export crop agriculture. *The Journal of Peasant Studies*, *27*(2), 50-93.

Raleigh, C., & Urdal, H. (2007). 'Climate change, environmental degradation and armed conflict'. *Political Geography*, 26(6): 674-694.

Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, *5*(1), 014010.

Scoones, I. (2009). Livelihoods perspectives and rural development. *The Journal of Peasant Studies*, *36*(1), 171-196.

Scott, J. C. (1976). *The moral economy of the peasant: Rebellion and subsistence in Southeast Asia*. Yale University Press.

Sen, A. (1981). *Poverty and famines: an essay on entitlement and deprivation*. Oxford university press.

Swindell, K., & Jeng, A. (2006). *Migrants, credit and climate: the Gambian groundnut trade, 1834-1934* (Vol. 12). Leiden-Boston: Brill.

Thompson, E. P. (1971). The moral economy of the English crowd in the eighteenth century. *Past & present*, (50), 76-136.

Tosh, J. (1980). The cash-crop revolution in tropical Africa: an agricultural reappraisal. *African Affairs*, *79*(314), 79-94.

Vaughan, M. (1987). *The story of an African famine: Gender and famine in twentieth-century Malawi*: Cambridge University Press.

Braun, J. V., & Kennedy, E. (1994). *Agricultural commercialization, economic development, and nutrition*. Johns Hopkins University Press.

Watts, M. (1983). Silent Violence: Food Famine and Peasantry in Northern Nigeria (Vol. 18). Berkeley. Cal.: University of California Press.

Watts, M. J., & Bohle, H. G. (1993). The space of vulnerability: the causal structure of hunger and famine. *Progress in human geography*, *17*(1), 43-67.

Witsenburg, K. M., & Adano, W. R. (2009). 'Of rain and raids: Violent livestock raiding in northern Kenya'. *Civil Wars*, 11(4): 514-538.

Wrigley, C. C. (1959). The Christian Revolution in Buganda. *Comparative Studies in Society and History*, *2*(1), 33-48.

CHAPTER 4

'Hunger Makes a Thief of Any Man':

Poverty & Crime in British Colonial Asia

Abstract

This chapter uses rainfall variation as an instrumental variable for padi-rice production to estimate the impact of poverty on different types of crime across British colonies in South and South East Asia (1910-1940). Using original primary sources retrieved from annual administrative and statistical reports, it provides some of the first evidence in a historical setting on the *causal* relationship between poverty and crime. Extreme rainfall, both droughts & floods, lead to a large increase in property crimes (such as robbery, petty theft and cattle raiding) but not to an increase in interpersonal violent crimes (such as murder, homicides and assault). In line with a growing body of literature on the climate-economy nexus, we offer evidence that loss of agricultural income is one of the main causal channels leading to property crime. Additional historical information on food shortages, poverty and crime is used to explore the connection in greater detail.

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4.1 Introduction

Climate change and its potential threatening impacts have spurred a growing body of literature examining how extreme weather conditions influence economic performance and human behaviour. This literature suggests that deviations from average rainfall and temperature levels increase the likelihood of intergroup conflict (Hsiang et al., 2013; Fjelde & von Uexkull, 2012), inter-communal conflict (Bai & Kai-sing Kung, 2011; Papaioannou, 2016), onset of civil war (Miguel et al., 2004; Blattman & Miguel, 2010), property crime (Mehlum et al., 2006; Iyer & Topalova, 2014; Blakeslee & Fishman, 2015), civil unrest and disobedience (Christian & Fenske, 2015) and even complete institutional breakdowns (Bruckner & Ciccone, 2011). However, some of this evidence has been contested on both theoretical (Buhaug et al., 2014) and methodological grounds (Sarsons, 2015; Klomp & Bulte, 2013), leaving the debate far from settled.

The societal impact of weather variability seems to be stronger and less ambiguous in developing regions, where the majority of cultivated crops are rain-fed and an insignificant share of cultivated areas is equipped with irrigation and artificial water drainage systems.[10] . Unfortunately, we still do not fully understand the underlying mechanisms driving the climate-to-economy relationship (Burke et al., 2015). The most commonly hypothesized channel is that of falling incomes and, by extension, poverty (Hsiang et al., 2013; Dell et al., 2014; Miguel et al., 2004). In a predominantly agrarian society –being primarily a rain-fed economy– economic prosperity is intimately tied to agricultural output. Extreme weather conditions –resulting in drought or flood– are associated with poor harvests and complete crop failures. Consequently, loss of a year's harvest, besides bringing about near-famine conditions, can easily push farmers into extreme poverty.

[10] Both types of water management systems are essential in tropical agriculture. After a flood, especially in areas that are flat and low-lying, water stagnates upon the soil rotting and eventually destroying the roots of the plants. Many scholars have pointed out that in this context 'a system of controlled drainage is more important than irrigation, while a combination of both is the ideal' (Lim, 1976, p. 43). Artificial drainage is, thus, necessary to circumvent surface run-offs, waterlogging, and other phytopathological diseases that impede root growth.

Poverty has long been a question of great interest within a wide range of fields. Multiple scholarly disciplines, including economics, political science, history and anthropology, have observed and documented that poverty and crime go hand in hand. The literature distinguishes between *absolute* poverty (i.e. lack of minimal material necessities for survival) and *relative* poverty (i.e. extreme income inequality). A great deal of previous research has demonstrated that absolute poverty is associated with higher property crime rates (Patterson, 1991; Miguel 2005; Mehlum et al., 2006; Iyer & Topalova, 2014), while relative poverty has been linked with the surge of aggression and violent crime (Blau & Blau, 1982; Kelly, 2000; Fajnzylber et al., 2002). Throughout this study, the term 'poverty' will be used in its broadest definition to encompass a wide range of conditions such as abrupt food shortages, starvation, hunger, subsistence crises and near-famine conditions.

In simple economic theory of crime, originally introduced by Becker (1974), individuals are more likely to become involved in criminal activity when they experience a negative income shock. This reasoning is framed in terms of an *opportunity cost model*; as income levels decline as a result of unfavourable conditions, engaging in crime becomes more opportune relative to participating in more 'peaceful' economic activities (Grossman, 1991; Seter, 2016). While the theoretical foundations of poverty and crime have been well-established, the empirical basis for such an argumentation is considered speculative at best (Dell et al., 2014; Burke et al., 2015). One plausible explanation for this omission is the endogenous relationship between poverty and crime: deteriorating economic conditions may favour criminal activity, since more people are likely to engage in crime as an alternative source of income, whilst higher levels of crime may undermine economic stability, investment and productivity. In other words, does poverty generate crime –or does crime lead to more poverty? Or does some third factor, for example state's institutional capacity or certain food policy reform, affect both simultaneously?

Previous studies have been unable to resolve the key econometric identification issues and have been potentially subject to bias due to reverse causality and omitted variables, both of which distort simple ordinary least squares (OLS) estimates either downward or upward. For instance, OLS estimates of the effect may be biased downwards if colonial governments are more likely to invest in food relief programs in districts that experience high crime rates, as these investments will underestimate the poverty-effect. On the other hand, OLS estimates of poverty on crime would be biased upwards if, for example, high crime rates bring about higher poverty. Likewise, an upward bias may result from third factors, such as the occurrences of political and economic crises, that tend to increase both crime and poverty simultaneously. In our findings we show that simple OLS estimates are, indeed, biased downward and underestimate the impact of poverty on crime to a substantial degree. Although this article's aim is to apply this approach in economic history, it may also be extended to more present day developing countries.

Ideally, one would need to pool reliable data from a comparable set of countries or administrative units within a similar agro-ecological setting (e.g. tropical agrarian economy), that rely on the same staple crop (e.g. padi-rice), and share a rather uniform institutional framework (e.g. British colonial rule) over a significant period of time (1910-1940). The colonial states in South and South East Asia suit these conditions (Figure 1).[11] Regardless of their multifarious differences, the unity we attribute to these states is their shared reliance on the same staple crop, rice, which was indisputably the most important food-grain in the economy (Hill, 2012; Bray, 1994; Farmer, 1977; Elson, 1997). And since we are mainly interested in states located within a similar agro-ecological setting, our scope will be confined to Asian countries that lie entirely within the tropics.[12] To that end, we retrieve uniquely rich data from primary sources to create a novel district by year

[11] Twenty seven states and districts were included in the analysis. The states include, the three Straits Settlements of Singapore, Penang, and Malacca; the four Malay states of Selangor, Perak, Negeri Sembilan, and Pahang which form the Federated Malay States (F.M.S.); Johore, Kedah, Perlis, Kelantan and Trengganu which collectively are known as the Unfederated Malay States (U.M.S.); North Borneo with its five administrative districts; the protectorate of Brunei; and Ceylon with its nine administrative districts. Sarawak had to be dropped due to lack of consistent data.

[12] India, for example, was not included since rice was largely competing with wheat as the main staple crop and almost half of its land lies outside the tropics.

panel dataset. Our analysis exploits high-frequency (e.g. year to year) changes in rainfall levels, rice production and several categories of crime.

Figure 1. *British Imperialism in South and South East Asia, c. 1914.*

Source: Created by the authors in ArcGIS.

Our key hypothesis is twofold: (a) if weather shocks lead to crime through subsistence crises, then these shocks should primarily affect the kinds of crime that alleviate loss of income. We argue that this may very well be the case in both rural and urban areas but for different reasons. In rural areas, farmers are *directly* affected by the deficient harvest and resort to illicit activities, whereas in urban areas, waged labourers have to cope with food price spikes, since they are much more dependent on the market for their daily calories (*absolute* poverty). (b) if weather-induced harvest failures are causing sharp increases in income inequality (relative poverty), for instance because some farmers or merchants benefit from exceptional market power during a period of food scarcity and food price hikes, we would expect more violent uprisings and grievances against people who were making money by exploiting the needs and misery of others. In other words, on the one hand, income losses caused by weather shocks should primarily increase petty theft and cattle raiding, and, on the other hand, perceptions of 'injustice', 'exploitation' or 'abuse' of miserable circumstances may induce a rise in violent crime such as homicides, murders and assaults.

This possibility is investigated by distinguishing between these two broad crime categories; i.e. property and violent crimes. We find that a one standard deviation *decrease* in annual rice production increased property crime by 21.2%. This effect is considerably higher in magnitude to accumulated evidence from other studies reviewed by Hsiang et al. (2013). There are three possible reasons why the effect is larger than that which the literature predicts. The first reason has to do with the institutional context in which this study is embedded and the limited attention the colonial governments paid to local food production.[13] Despite the fact that by the early twentieth century most colonial governments were taking a more activist approach to promoting widespread economic development in the territories they controlled (Booth 2012), it remains highly refutable the extent to which they managed to convert growing national output into improved living standards for the vast majority of local population. Colonial government expenditures on transport infrastructure, food relief programs and irrigation/drainage systems remained considerably low in per capita terms.[14] Conservative fiscal policies and the enduring food vs. cash crop substitution dilemma among colonial officials impeded local padi-rice cultivation and substantially increased reliance on imported foodstuffs (Lim, 1977; Elson, 1997).

A second reason why the effect was so large has to do with the substantially low living standards prevailing among rural communities at the time. While exports may have boomed and government revenues expanded, nutritional intakes for the mass of the population did not improve, and as a result mortality rates were high (Booth 2012). That the effect between rainfall shocks and property crime rates declined considerably throughout the twentieth century, suggests that modern economic growth and its ensuing technological improvements in agriculture have enhanced the ability of vulnerable rural societies to withstand climate-induced calamities. Lastly, in seeking to explain the high magnitude of the effect, it should

[13] For instance, in British Malaya around two thirds of total rice availability was supplied by imports, mainly from Thailand and Burma.
[14] See Booth (2012) for a detailed discussion on fiscal spending variation across colonial systems in South East Asia.

be reasoned that we are dealing with a non-industrial part of the world, where the vast majority of the total income was derived from agricultural practises, and where wage labour opportunities were limited, and wage rates low. (Drabble, 1974; Farmer, 1977; Bray, 1994; Elson, 1997).

In line with our second hypothesis, it is found that the effect of poverty on violent crimes was insignificant and nearly zero, suggesting extreme income inequality was not (as) crucial in inciting crime. Additionally, it is shown that a standard deviation decrease in rice yields increased begging and vagrancy by 13.8%, suggesting that rice production was a key determinant of poverty during this period.

This study yields three contributions. *First*, we find strong evidence that both drought and excessive rainfall cause substantial increases in property crime. The results are robust to using alternative econometric specifications, to using lagged dependent and independent variables, to cross-sectional spill-overs, and finally, to clustering standard errors at the country level, the year level as well as two-way clustered at both the country and the year level. These results are in accord with recent studies indicating that property crimes are more likely to increase in years of depressed incomes than violent crimes (Blakeslee & Fishman, 2015; Iyer & Topalova, 2014; Melhum et al., 2006; Miguel, 2005), as well as with simple economic theory of crime (Becker, 1974; Grossman, 1991; Bourguignon, 2000).

Second, a causal relationship is established between poverty and property crime in an agrarian historical setting, and the channel of causality identified by using rainfall as a source of exogenous variation in food production. While it is intuitively plausible that the rainfall instruments are exogenous, we have to evaluate whether they satisfy the exclusion restriction: rainfall shocks should affect property crime only through reduced agricultural production. One potential concern may be a direct causal link (without any changes to real income) between high temperatures and aggressive and/or violent behaviour, as several psychological and empirical studies have documented (Anderson, 1989; Anderson et al., 2000; Ranson, 2014; Iyer & Topalova, 2014; Blakeslee & Fishman, 2015). Our results confirm this direct extra-economic channel, since high temperature shocks are associated with more violent crimes (coeff.= 0.043, s.e.= 0.018). However, temperature shocks yield no association with property crimes nor with adverse effects on food production. This serves as an important validation of the empirical strategy and highlights the importance of looking beyond aggregate crime measures in this climate-crime literature, since they may shadow heterogeneous patterns across crime categories.

A further violation of the exclusion restriction is the possibility that rainfall deviation may have a direct effect on crime itself; if heavy rains, due to flooded roads for instance, reduce criminals' likelihood of being detained by the police or hamper police' capacity to report crimes. Therefore, if such channels are present, IV estimates could misattribute the direct effects of rainfall to crime. Note that such channels are not serious threats to our estimation strategy, since excessive rainfall is empirically associated with significantly more (not less) crime in the reduced-form regressions. Thus to the extent that a bias exists, our estimates would be lower bounds on the true impact of poverty on property crime.

A critical assumption underlying the use of rainfall as an IV is that rainfall shocks affect property crime only through their impact on *agricultural income*. The most prominent critique put forward for such an assumption is that rainfall shocks could also potentially operate through non-agricultural urban channels (manufacturing and non-agricultural wages). However, these channels are unlikely to be important in the agrarian and largely non-industrial context studied here, where rain-fed agriculture dominates aggregate production and a relatively small amount of urban labourers existed (Parmer, 1960; Tregonning, 1965; Drabble, 1974; Bruton, 1992). It is acknowledged that our identification strategy may be inappropriate for other more developed regions of the world, where rainfall shocks are not sufficiently related to depressing agricultural income, for instance, due to substantial investment in irrigation and drainage infrastructure absorbing such shocks (Sarsons, 2015). Nevertheless, this strategy is likely to be of interest to both economic historians and policy makers, since it is highly viable for poor agrarian societies, such as pre-industrial Europe or contemporary less developed countries.

Third, we make use of additional historical information on food shortages and crime as reported in the colonial sources. This is a substantial contribution since most studies in this field are solely based on econometric correlations and make no attempt to contextualize their findings using qualitative evidence. Using a systematic approach, we were not only able to confirm the empirical findings of this study but to find support in favour of the theoretical foundations of the opportunity cost model. We observe that as foodstuffs become scarcer and distress levels rise, property crimes and vagrancy inflate substantially –while violent crimes remain unaffected.

Our work also relates to the emerging literature on the effects of weather shocks on crime and conflict. Interestingly, the vast majority of the studies published on the climate-economy nexus has been mostly restricted to limited comparisons in the post-1960 period, mainly due to data availability (see Hsiang et al., 2013; Dell et al., 2014). Only very recently have scholars begun expanding the temporal scope in the pre-1960 period (for example Bai & Kai-sing Kung (2011) and Jia (2014) for premodern China; Anderson et al. (2015) and Bignon et al. (2016) for premodern Europe; Papaioannou (2016) and Papaioannou & de Haas (2015) for colonial Africa). This study thus expands both the geographical as well as temporal scope of studies on the climate-economy nexus.

The remainder of the paper proceeds as follows. Section 2 reviews the historical context and the colonial reports. Section 3 describes the data sources and the construction of variables used in the analysis, and Section 4 lays out the empirical strategy. Sections 5 presents the empirical findings and Section 6 concludes.

4.2 Historical Context

In examining the possible mechanisms underpinning the relationship between food shortages, poverty and crime in British colonial Asia, it is important to consider some of the underlying agricultural, economic and political conditions. We begin by providing a brief historical background, including a discussion of the importance of rice production and various aspects of the British colonial rule. We then proceed by reviewing the colonial reports are then reviewed in order to offer further contextualization, illustrate underlying mechanisms and validate the theoretical foundations of the *opportunity cost model*.

4.2.1 Historical Background

During their long history as agrarian societies, South and South East Asian states were very vulnerable to unfavourable climatological conditions (Hill, 2012; Bray, 1994). Peasant agriculture failed to rise above subsistence level during the period of British rule (Tregonning, 1965; Bruton, 1992). Crops continued to be adversely affected by natural enemies and there were limited agricultural advances to increase yields as the peasant's technology had changed only slightly over the years . Growth of agricultural production was further impeded by the rapid expansion of rubber cultivation in the early twentieth century (Drabble, 1974; Elson, 1997; Bray, 1994). Despite padi rice being the traditional staple crop in this part of the world, the quantities produced were sometimes described as being inadequate to meet the wants of the people who grow it and several states were, to various degrees, dependent on imported agricultural produce (Farmer, 1977; Butcher, 1979). However, padi rice production formed the principal occupation of the peasant, and was the chief source of general prosperity (Lim, 1976; Elson, 1997).

Many historians have observed that deep in the peasant's ethos was the conviction that padi-rice was the foundation of life and its cultivation the proper and most honoured sphere of toil, as emphasized by Farmer (1977) and Bray (1994), when they report that "*to be a cultivator very nearly meant to be a padi cultivator*". As Hill (2012, p. 59) puts it "*the Malaya states were predominantly agricultural and rice-growing was so prevalent that it had led to the virtual exclusion of any other food crop"*. For most Malaya states the proportion of rice growers to total economically active persons was above 80 per cent. Nevertheless, the Malays did not attempt double-cropping as wet land rice required so long a period to reach maturity, that there would have been a deficiency of water for a second crop. In cases where a second, light crop was attempted, "*it often scarcely repaid the trouble of cultivation; so poor was its yield*" (Hill, 2012, p. 111).A similar story can be deduced from Mills (1964) and Bruton (1992) for Ceylon, and from Tregonning (1965) for North Borneo. Tregonning (1965, p. 93) points out that '*although the area devoted to rice cultivation was greater than that given to any other crop and its culture was the chief industry of the native people, there was never enough rice produced for the territory to be self-sufficient, and large quantities were always imported*'.

The significance of padi-rice cultivation for the overall well-being of the native population was also documented in the colonial sources. As we will see in more detail in the next section, the agricultural commissioners were required to report whether food supply was sufficient and well maintained to cover local needs. If rice production was scarce, they were requested to provide plausible explanations. Time and again, they pointed to climatological conditions in explaining the deficiency or failure of the annual padi-rice harvest and its consequential distress among smallholders.

The basic function of British colonisation in the Asian states covered by this study, whatever its form and origin, was to establish and maintain the conditions under which the dynamic forces of trade could flourish (Lange, 2004; Mills, 1964; Parmer, 1960; Butcher, 1979; Wade, 1990). Although the British rule was intended to be indirect, direct rule was the practice and it increased in scope and effectiveness as the years passed. The new structure was purely British in conception and operation. British interests dominated the vast majority of commercial activities as the British owned most of the plantations, the estate factories processing the rubber, tea, and coconuts, the import-export trade, and other service activities. In areas with favourable soils and climates, cash crop export economies (such as coffee, tea, rubber etc.) were encouraged and promoted as they provided the colonial authorities with much needed revenue from customs duties and other forms of indirect taxation (Drabble, 1974; Booth, 1999).

4.2.2 Qualitative Evidence: Climate, Poverty and Crime

The sources used are the annual reports filed by the colonial administration. The British colonizers set up an extensive system of administration, where elaborate administrative accounts were kept. These accounts make regular notice of weather-induced agricultural failure resulting in higher levels of social distress, and in more extreme cases, subsistence crises and near-famine conditions. In practice, each department filed reports to provide information on and explanations of various incidences along with what was considered to be their causes. The goal of this section is not to systematically record all incidences of food shortages, subsistence crises, and crime, but rather to give a detailed contextual overview of the reasons, mechanisms and channels appearing to be most relevant.

(a) Rainfall Extremes: Flood & Drought

In considering the impact that unfavourable weather conditions have on annual food production, it is important to stress the non-linear nature of the relationship. Based on primary sources, we argue that both *excessive rainfall* and *droughts* have been responsible for bringing about deficient padi rice harvests. The sources abound with examples of the curvilinear nature of the effect. For instance, the agricultural commissioner of Kedah, in his 1925 report, emphasises both types of environmental hazards in reducing farmers' welfare:

> *a drought at the wrong season or a flood will cause great loss to the country and to the padi planters. It was at one time roughly estimated that the present year's padi crop would, owing to drought, be some 25.000.000 gantangs of padi short of the previous year's gantang. As a result it would involve a prospective loss of $2.500.000 to padi planters*.
> (Kedah *Annual Report*,1925).

In 1934, the same commissioner reported a severe crop failure, owing this time to excessive rainfall: "s*erious flooding was experienced during November and early December, doing extensive damage in several districts, and it is believed that the harvest will be less* *abundant than that of the previous year*". His speculation came true by the end of that year when "*the total yield was just about 33 million gantangs, showing a decrease of 17 million gantangs as compared with 1933*" (Kedah, *Annual Report*, 1934).

Likewise, in 1924, the Kelantan colonial official recorded both types of unfavourable weather conditions within the State and remarked that "*the high variability of yields has been connected chiefly with droughts and floods. As one reads back through the annual reports, one constantly comes across reports of disastrous droughts. At other times it is an early flood which has drowned the padi before it has become sufficiently established.*" The rice returns reveal that "*the total production of rice has fluctuated rather more violently than the area planted, and sometimes in an opposite direction. Thus in the 1924 season the 148.000 acres yielded only 55,359 tons, whereas last year the 139,000 acres yielded 74,008 tons* –a decrease in production of ca 25%. The reason for such a decrease was the "*serious flooding during the early part of the season made it impossible for peasants to cultivate their land*". Thus, overall, our qualitative evidence supports a U-shaped parameterization of the link between weather and agricultural incomes.

(b) Food Scarcity & Price Spikes

The annual reports are very extensive and meticulous in their description of local agricultural conditions. These reports frequently mention the adverse consequences of weather conditions in inducing food shortages, food price hikes and resultant social distress. Shortages of rice and other foodstuffs, and subsequent increases in their prices were greatly felt by the people. In years of food scarcity, local padi-rice was sold for high prices, which were beyond the means of the poor.

An illustrative example is taken from the annual report of Trengganu in 1914 where the padi harvest, due to abnormally high rainfall, was a very poor one, resulting in substantial shortage of food supply among the local population. . It is important to note that such adverse conditions should be viewed in a context where already "*the rice grown in Trengganu is far from sufficient for the support of the population*". A shortage of rice resulted in a "*sudden panic in the market inciting food-price spikes and thus making food inaccessible to most farmers*". That year the price of rice had risen from $14 to $27 a bag —an increase of about 100%. The colonial official concluded that "*with the high prices which prevailed the native had a hard time to make both ends meet and a certain amount of distress has been apparent*". The social consequences of such conditions can be depicted best through the annual police report of 1914, which recognized:

> *that there was a large increase in the number of offences against property. A number of causes are given for this increase...among them the most probable seem to be economic due to unfavourable weather conditions. The last reason applies more particularly to the surrounding plain, where thieves and house-breakers, when detected, are usually found to be young padi planters* (Trengganu, *Annual Report*, 1914).

Similarly, the agricultural commissioner of Central province in Ceylon recounted in 1927 that "*the padi-planters are going through a year of almost unprecedented misfortune*" and that "*the abnormal rainfall in January did considerable damage. That was a truly phenomenal rainfall. Paddy cultivation has been a failure —one of the lowest crops on record, and it was followed by the usual food shortage. This is also shown by the fact that burglars take away foodstuffs, which formerly were left behind. Owing to the shortage of paddy crops the price of paddy has risen dramatically. Deaths from starvation are occasionally reported*". Indeed, the rice crop was a poor one and totalled 300.000 gantangs as compared to 1.200.000 the year before –a decrease of ca 75% (Ceylon, *Annual Report,* 1927).The following two cases were selected to offer a comprehensive impression of the far-reaching impact of rice shortages on the vast majority of households, across numerous aspects of ordinary life, regardless of whether they were net rice importers or exporters. One could hypothesize that the effect might be stronger in rice importing districts, as the available food supplies did not meet local demand. Thus, when the already insufficient padi-rice harvests fail, economic distress would be inflated. By contrast, one could argue that the effect might be stronger in rice exporting districts, as the annual rural income of households would be more exposed and sensitive to weather fluctuations. Thus, a failed rice harvest would have a relatively more acute impact on rice exporting districts than in rice-importing ones. While these dynamics are more systematically addressed in the econometric part of the paper, we illustrate the broad social impact of rice shortages in cases where rice was exported and imported.

For instance, in Selangor (a rice importing state), when the rains failed and available incomes shrank, "*the health of the people deteriorated and fell considerably below the normal standard. This was to a large extent due to the acute scarcity of food. Enteric cases soared in almost all towns*"(F.M.S. *Medical Report,* 1919). Similarly, in 1936 Kedah (a rice exporting district), the adverse effects of food scarcity were felt on the general welfare of the people. Infant mortality rose by 11% and average daily attendance at government schools declined from 13.425 in 1935 to 9.912 in 1936 (approx. 27% decrease). "*The decrease was due to the scarcity of rice and the poverty of the people. Children were in many cases half starved, and their parents could not provide them with clothes*". (Kedah, *Education Report*, 1936).

(c) Poverty & Property Crime

Poverty has been put forward as a decisive motive for crime. Individuals lacking the basic means of subsistence are more likely to become involved in criminal activity when they experience a negative income shock. As income levels decline, engaging in property crime becomes more opportune relative to participating in more 'peaceful' economic activities and the stolen property might be regarded as a buffer in alleviating distress. This kind of criminal behaviour was frequently stated in the annual reports and can be illustrated best in the words of the colonial Administrator of Southern Galle of Ceylon, who in 1931 observed that:

> *there is a great temptation to them* [padi-growers] *to commit crime in order to live; and reports received indicate that there has been an increase of cattle-stealing and theft of foodstuffs. Thefts of foodstuffs have not been common in the past, and the increase in this type of crime and in cattle-*

> *stealing is due to real poverty and difficulty in obtaining food* (Ceylon, *Annual Report*, 1931).

A similar conclusion was reached by the chief Commissioner of North Borneo in 1919, who stated that:

> *the year was probably the worst ever experienced in the State. The difficulties to be faced were great. Crop after crop was destroyed and by June the shortage of food was becoming very serious. Theft was rife and increased as food became short* (North Borneo *Native Affairs*, 1919).

These two examples serve to highlight the idea that when farmers realize their food yields are going to be deficient or entirely failed, the opportunity cost of crime is reduced and thereby increase its incidence. The more one reads into the reports the better insights he gets regarding reasons behind the steep increases in property crimes. When the harvest fails and food becomes scarce, local farmers, in need of food, may resort to plundering and stealing either in the form of cash or kind on condition that it could alleviate distress. The Chief of the Police of the Malacca settlement, in 1936, summarized that:

> *The number of offences against property –cattle lifting, burglary, and petty thefts–has sown a most unsatisfactory tendency. This is doubtless due to the scarcity of food. I have heard it said that the way in which private gardens are rifled is a real deterrent to enterprise in their cultivation. This may be an exaggeration, but the evil is rampant, and in some cases is caused by real starvation.*

His counterpart in the Malay Peninsula, in his 1932 report, also associated the steep increase in property crimes of that year with the widespread shortage of food, stressing that when house breakers and thieves were detected, they were usually found to be young padi planters. In one of his journeys up country, the chief of Police recounted that:

> *it was impossible to obtain padi in the villages…The harvest was late, the crops were entirely ruined...rice crops were everywhere poor and in many places destroyed by the phenomenal drought...The presence of property crime is undoubtedly due in no small measure to a shortage of rice* (F.M.S., *Judicial Report*, 1932).

Few would dispute that livestock breeding broadens the opportunities to store wealth, mediate risks and raise land productivity in pre-industrial societies. However, livestock was also seen as an object of looting, since by stealing few cattle in times of hardship the perpetrator gains either income by marketing the cattle and exchanging it for other goods, or gains calories by simply consuming it. This is exemplified best in the report undertaken by the colonial officer of Trengganu state in 1931, who related the unfavourable weather conditions of that year with a considerable rise in arrests, stressing that many parts of the central plain were "*so infested with thieves that poultry and cattle could not be kept and was stolen by night*".

In many instances the colonial officials associated food shortages directly with cattle-raiding noting that "*there was an increase of cattle theft, perhaps due to the shortage of food. Most cattle stolen are slaughtered*" or that "*cattle stealing was rife in North Kedah during the first nine months of the year owing to the unfavourable weather conditions of the country in certain localities.*"

Simple theoretical considerations suggest that income shocks should have a larger impact on property crimes as compared to violent ones. Our qualitative material confirms that logic, as the colonial officials reported sizable differences between the amount of property and violent crimes within the same year. We observe many instances where increases in property crime did not yield concurrent increases in violent crimes. According to the 1919 Annual Report, Kedah had "*experienced in succession the two driest years since rainfalls were first recorded in 1906*" and as is anticipated, the padi crop reaped at the beginning of 1919 was poor. Theft returns that year more than doubled; from 403 up to 812 cases –an increase of more than 100%, whereas the violent offences against the person declined substantially. The Commissioner reports that "*there is a large amount of petty thieving but there are remarkably few crimes of violence.*"

The evidence presented thus far supports the idea that scarcity of food and loss of income had led to substantially more property crime. However, unlike years of extreme weather fluctuations, there have also been seasons with exceptionally good yields. The impact of 'feast' seasons on reducing crime levels was noted by the colonial administrators as well. In years where the precipitation patterns were smooth, the rice-harvest was bountiful, and as a result crime rates plummeted. According to the 1930 Agriculture report of Kelantan: "*the crop was harvested under ideal weather conditions and proved to be one of the best secured for a number of years. A surplus over the requirements of the indigenous population was obtained.*" According to the Police report of that same year "*There has been little serious crime, owing to prosperous favourable weather conditions.*"[...]"*as regards criminal litigation, increased prosperity has led to diminution of crime*" (Kelantan, *Police Report*, 1930).

4.3 Data

The data were obtained from colonial administrative accounts (Annual Reports and Blue Books of Statistics) collected over a long research visit at The National Archives (TNA) in London. All variables are original and obtained directly from colonial sources, except if stated otherwise. The summary statistics are presented in Table 1 below. Panel (*a*) includes the main dependent variables of crime. Panel (*b*) includes the weather measures and their multiple modifications. Panel (*c*) reports padi-rice production and panel (*d*) includes few time-varying controls. All variables are available annually at the district level between 1910 and 1939.

Table 1. *Summary Statistics: District by Year*

Variable	Obs.	Mean	Std. Dev.	Min	Max
Panel (a): Crime measures per 100,000 population					
Ln(Property crime)	659	2.41	0.40	0.50	3.69
Ln(Violent crime)	683	2.14	0.46	0.90	3.25
Ln(Theft)	610	2.30	0.45	0.42	3.69
Ln(Cattle-raiding)	417	1.99	0.39	0.88	3.02
Ln(Assault)	682	2.09	0.50	0.42	3.21
Ln(Homicides)	695	0.89	0.49	-0.68	2.33
Ln(Vagrancy)	339	0.69	0.57	-0.39	2.22
Panel (b): Weather measures					
Rainfall deviation Stations (z-score)	627	0.00	1.00	-2.42	3.19
Rainfall deviation squared Stations	627	1.00	1.44	0.00	10.23
Rainfall *absolute* deviation Stations (linear)	627	0.79	0.63	0.00	3.19
Positive rainfall shock (1 std dev)	627	0.17	0.37	0.00	1.00
Negative rainfall shock (1 std dev)	627	0.15	0.36	0.00	1.00
Rainfall deviation Grids (z-score)	780	0.00	1.00	-2.87	3.38
Rainfall deviation squared Grids	780	1.00	1.40	0.00	11.47
Rainfall *absolute* deviation Grids (linear)	780	0.80	0.59	0.00	3.38
Temperature deviation (z-score)	780	0.00	1.00	-2.25	3.05
Panel (c): Food measure					
Padi rice production (z-score)	682	0.00	1.00	-3.26	3.62
Padi rice cultivation in acres per capita	682	0.56	0.33	0.06	1.26
Panel (d): Controls (time-varying)					
Ln(Population density)	810	4.25	1.56	-0.33	8.09
Ln(Road density)	810	-2.12	2.60	-8.61	4.75
Ln(Police staff density) per 100,000 population	797	5.06	0.51	3.81	6.25
Cash crop production in value (£) per capita	780	13.11	6.49	2.41	28.31

4.3.1 Crime data

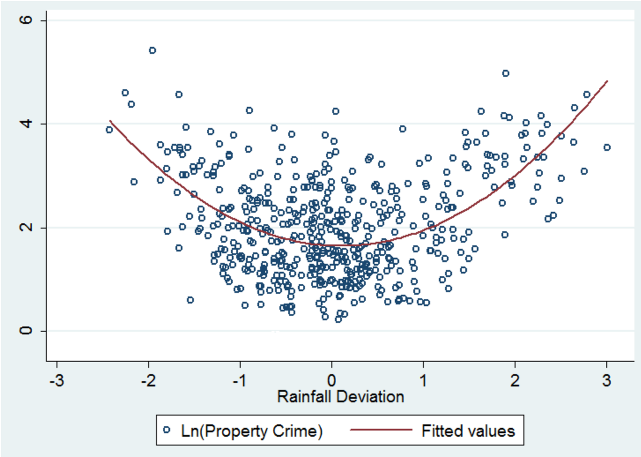
Among the crimes included are theft, cattle-raiding, assault and homicide. Of the crimes included in the data, we combine individual crime categories into two broad categories: theft and cattle raiding as *property crimes*, and assault and homicide as *violent crimes*. Results are presented for both individual and aggregate crimes. Additionally, data is obtained for vagrancy for each state they were available. All variables exhibit a high year-to-year variation. Table A-1 presents the pairwise correlation matrix among the dependent variables. In thinking about issues of differential crime reporting over time, it is important to note that we have no evidence to believe that weather shocks would affect the incentive of crime victims to report crime or the incentive of colonial officials to record more or less criminal incidences. Even though it is not implausible that local authorities would in fact increase the level of under-reporting at precisely those times when crime is rife —

i.e. after an adverse weather shock— we argue that this tendency would, if anything, downward our results.[15] The summary statistics for the types of crime are presented in panel (*a*) of Table 1.

4.3.2 Weather shocks

Historical precipitation data come from meteorological stations, which were first introduced by the British in the late nineteenth century. The data were consistent throughout the period of interest. Since all districts had at least one meteorological station within its borders, it has been possible to include all colonial districts and states. If more than one station was in place, we took their average of them. The measure of weather shocks applied here is the annual standardized *rainfall deviation* from the long-term panel mean of rainfall for a given district. Values for standardized *rainfall deviation* have a mean of 0.00, a standard deviation of 1, and range from -2.42 to 3.19. Figure 2 shows how the relationship looks when we scatter plot property crime (*fitted values in purple*) against rainfall deviation (*x-axis*).

Figure 2. *Rainfall Shocks & Property Crime*



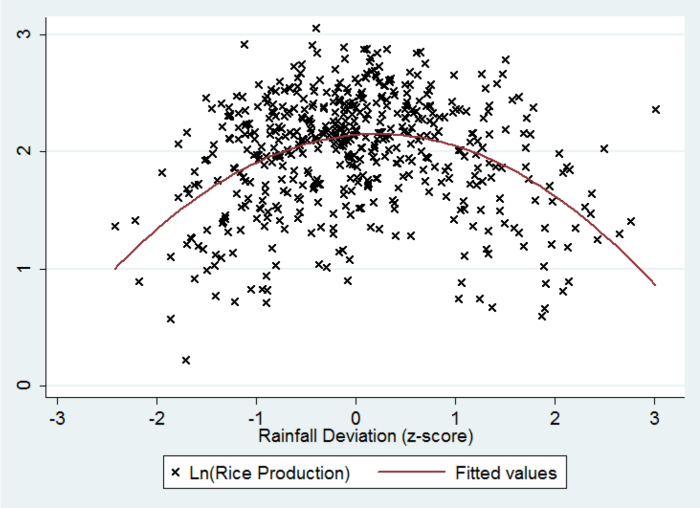
[15] We are aware of potential inadequacies and biases in the colonial sources (e.g. the possibility that the district officials would consistently under-report issues to look great to their superiors). In section 2.2, we were able to match several unfavourable weather conditions with widespread distress and related property crime, while we were able to identify a null effect on violent crimes. If this bias of under-reporting exists in the case of British Asia, and negative income shocks cause households to under-report crime, our estimates would underestimate the true causal impact of poverty on crime. Moreover, the functional use of the archival sources enabled us to obtain a more thorough understanding of the important mechanisms driving the relationship of interest, and to add a new layer of robustness by backing up the regression results.

Since there are many ways to parameterize rainfall, we also transformed our main explanatory variable, and defined a "negative rainfall shock" as a dummy which takes the value of 1 when annual rainfall in a district *i* is one standard deviation below the long-run mean of panel *i*, and a "positive rainfall shock" as a dummy being one standard deviation above the panel's mean. We also use an alternative measure of rainfall taken from the Willmott and Matsuura (2009) database. The data have 0.5° latitude by 0.5° longitude grids. Values for standardized *grid rainfall deviation* have a mean of 0.00, a standard deviation of 1, and range from -2.87 to 3.38. Although this measure gives nearly identical results, it reduces (a) our sample size considerably (Singapore, Perlis and a few districts in North Borneo had to be dropped due to lack of observations) and (b) the accuracy of the observations as the data compiled in this dataset is mostly based on extrapolation. Lastly, we construct a variable of temperature deviation to account for the extra-economic direct impact of extreme heat on crime. The summary statistics of the weather conditions are presented in panel (*b*) of Table 1.

4.3.3 Rice production

District level agricultural data on padi rice yields were obtained from the *Agricultural Annual Reports* for each state. We create a consistent indicator of gantangs of rice per capita for each district in our sample. As discussed above, peasant agriculture failed to rise above subsistence level during this period of British rule (Tregonning, 1965; Drabble, 1974; Bray, 1994; Mills, 1964). Padi-rice yielded only one harvest a year in this part of the world at the time and peasants did not attempt double-cropping (Elson, 1997; Lim, 1973; Bruton, 1992). Therefore, tying annual rainfall deviations to padi-rice production becomes straightforward. Figure 3 graphically presents the strong negative correlation between rainfall shocks and rice production between 1910 and 1939. It is evident that as rainfall deviates from the long-term average in either direction, food production is shrinking.

Figure 3. *Rainfall Shocks & Food Production*



4.3.4 Controls

While omitted variables should not be of great concern, a number of additional time-varying controls have been included to address potential bias stemming from unobserved factors. We control for differences in (a) state capacity by constructing a measure of road density following Herbst (2000), (b) policing capacity by constructing a measure of police staff density (Papaioannou, 2016), and (c) demographic pressures by constructing a measure of population density. Lastly, we control for the interaction of a few spatial characteristics of districts with a linear time trend to take into account their heterogeneous impacts over time. We construct a battery of district-specific effects to control for the possibility that some districts would react differently over time. It should be reminded here, that we are dealing with a timespan of about three decades, and we, therefore, expect some unobservable characteristics at the district level to change over time. Thus, by including the interactions of district dummies and a linear time trend, we allow the estimates to take into account widening differences across regions and districts during the long time horizon of this study. For instance, we expect that the colonial authorities in the early 1940s (as compared to the early 1910s) to have extended their capacity to broadcast power and to have become more effective in opposing crime. In addition, it could be that a spike in property crimes in district *i*, may have urged the colonial authorities to invest more in those crime-stricken places and, as a result, in the following years the capacity of police in inhibiting future crime would have been increased. In either case, not accounting for such systematic tendencies in the data might have yielded inconsistent estimates.

4.4 Empirical Strategy

We first establish that rainfall shocks significantly affect crime rates (reduced form specifications) and then proceed by focusing on identifying the causal channel linking poverty and crime (first-stage and IV-2SLS results).

To achieve our first goal, the regression specification (reduced form) is as follows:

$$Ln(Crime)_{i,t} = \beta_0 + \beta_1 \, AbsoluteRainfallDeviation_{i,t} + \delta Z'_{i,t} + \nu_i + \mu_t$$
$$+ (District\ dummy \times Time\ Trend)_{i,t} + \varepsilon_{i,t} \qquad (1)$$

where $Ln(Crime)_{i,t}$ denotes the natural log of the incidence of the various types of crime (per 100,000 population) in district i and year t. $AbsoluteRainfallDeviation_{i,t}$ denotes the annual *absolute* rainfall deviation of each district i from the historical long-term mean of the same district. $Z'_{i,t}$ denotes a vector of controls to avoid any potential omitted variable bias. ν_i and μ_t are district and year fixed effects, respectively. We use these to control for omitted heterogeneity at the level of districts and time periods. These controls are quite crucial in controlling for unobservable time-invariant district heterogeneity and for factors that may affect the levels of crime across all districts in the same year (such as during the Great Depression). Moreover, $(District\ dummy \times Time\ trend)_{i,t}$ denotes the unobservable district characteristics (ν_i) when interacted with a linear time trend (t). In practice, we control for district-specific characteristics to capture district-specific changes in crime activity over time. A good example here, is changes in district capacity to report and restrain crime over time, since police authorities in highly criminal districts may become more efficient in preventing crimes.

The coefficient of interest, β_1, is the estimated effect of a one standard deviation change (either positive or negative) in rainfall on crime. A positive sign, $\beta_1 > 0$, indicates that, on average, extreme rainfall shocks are associated with more crime. In all estimations we cluster standard errors at the district level (no. of clusters = 27) to avoid any autocorrelation concerns of weather shocks and the possibility of measurement errors, which are more likely to be correlated within districts across time. For robustness, we cluster standard errors at the country (no. of clusters = 9) and at the year level (no. of clusters = 30) as well as both country-year level by two-way clustering. This way we avoid concerns about country-year unobservable characteristics that vary across time, such as levels of expenditures on law enforcement, or country's capacity to record crime rates.

In addition, we control for spatial correlation (cross-sectional dependence) by adjusting standard errors following Hoechle (2007). To assess the importance of omitted variable bias we build on the method recently developed by Oster (2014) and Gonzalez & Miguel (2015), by estimating the reliability ratios. In practice, we show that the coefficient estimates on crime change little across regression specifications with and without additional covariates. To give one example, the estimated coefficient of rainfall deviation on theft when we include the full set of observable controls is 0.1098 with an $R^2 = 0.473$ (column 1 of Table 2). The same coefficient from the uncontrolled regression (not reported in the text)is 0.1181 with an $R^2 = 0.369$. Calculating the proposed equation (2) in Gonzalez & Miguel's (2015) study, we get an adjusted lower bound coefficient of 0.1016 and upper bound of 0.1098. Such a finding implies a highly stable coefficient. The same approach was followed for the other coefficients, yielding similar results (not reported).

In achieving our second goal and identifying the causal effect of poverty on crime, we present the OLS first-stage relationship results between rainfall and food production, and then perform a IV-2SLS estimation using rainfall as an instrumental variable for food production. While few scholars have put the use of rainfall variation as instrument for income under scrutiny (Sarsons, 2015), by pointing to alternative non-agricultural channels (e.g. urban wages or direct psychological effects) through which rainfall shocks may increase crime, a large body of literature argues that the use of this kind of instrumentation approach in rainfed agrarian settings is highly suitable (Miguel et al., 2004; Miguel, 2005; Dell et al., 2014; Mehlum et al., 2006). In either case, we conduct several robustness checks to address potential violations of the exclusion restriction (section 5.4).

4.5 Main empirical results

The first part of this section (4.5.1) presents the results on the impact of weather shocks on the various types of crime (reduced form specifications). Section 4.5.2 presents the results of the instrumental variable approach (first-stage and two-stage IV-2SLS). Section 4.5.3 presents a set of heterogeneous effects for different sub-samples. Section 4.5.4 presents the results for a set of robustness checks and section 4.5.5 refutes potential violations of the exclusion restriction.

4.5.1 The Impact of Weather shocks on Crime (Reduced-form)

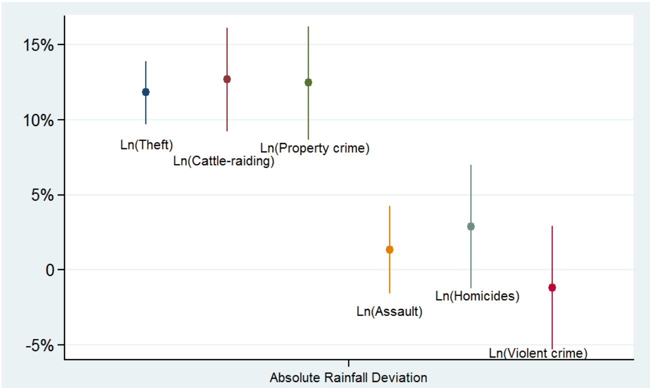
The results are presented in Table 2. In the reduced-form regression, a one standard deviation change in rainfall is associated with significantly more crime, 10.9% for thefts (column 1 in Table 4), 10.5% for cattle raiding (column 2), and 11.25% for property crimes (column 3) while it yields no significant effect for assaults (column 4), for homicides (column 5), and for violent crimes (regression 6). Their regression coefficients as well as their standard errors range are presented in Figure 4.

Table 2. *The Impact of Rainfall Shocks on Crime (Reduced-Form)*

	Thefts	Cattle Raiding	Property Crimes	Assaults	Homicides	Violent Crimes
	(1)	(2)	(3)	(4)	(5)	(6)
Absolute Rainfall Deviation *t*	0.109***	0.105***	0.112***	0.014	0.025	-0.043
	(0.010)	(0.018)	(0.017)	(0.013)	(0.018)	(0.130)
District & Year FE	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y
District-specific effects (District dummy × Time trend)	Y	Y	Y	Y	Y	Y
No. observations	596	417	576	605	580	600

Notes: *Significant at 10%, **5%, ***1%. Sample period: 1910–1939. OLS-FE. The dependent variables are the logarithm of each crime variable expresses as 100.000 of the population. Reported in parentheses are standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicate the interaction of each District dummy × Time trend.

Figure 4. *Magnitude of Coefficients*



Notes: Regression coefficients of Table 2. Confidence Intervals set at 95%.

Table 3 presents the results when we include lagged and lead weather conditions as determinants of crime. The coefficient of rainfall shocks on property crime remains stable (about 11%) and robust to the inclusion of rainfall lag (*t - 1*) and lead (*t + 1*) (columns 2 & 3). Columns 4 to 6 show that rainfall shocks do not impact on violent crimes.

Table 3. *The Impact of Lagged and Lead Rainfall Shocks on Crime*

	Ln(Property Crime)			Ln(Violent Crime)		
	(1)	(2)	(3)	(4)	(5)	(6)
Absolute Rainfall Deviation *t*	0.112***	0.111***	0.102***	0.007	0.006	0.017
	(0.017)	(0.016)	(0.017)	(0.012)	(0.014)	(0.014)
Absolute Rainfall Deviation *t - 1*		0.019			0.023	
		(0.015)			(0.013)	
Absolute Rainfall Deviation *t + 1*			-0.004			-0.001
			(0.021)			(0.008)
District & Year FE	Y	Y	Y	Y	Y	Y
Controls (time-varying)	Y	Y	Y	Y	Y	Y
District-specific effects (District dummy × Time trend)	Y	Y	Y	Y	Y	Y
No. observations	576	502	502	600	518	518

Notes: *Significant at 10%, **5%, ***1%. Sample period: 1910–1939. OLS-FE. The dependent variables are the logarithm of each crime variable expressed as 100.000 of the population. Reported in parentheses are standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicate the interaction of each District dummy × Time trend.

Next, we present the results solely for property crime, since that is our main dependent variable of interest.[16] In Table 4, we include the square term of $RainfallDeviation_{i,t}$ and find that the effect of rainfall shocks on property crime is curvilinear (U-shaped), meaning that both drought and excessive rainfall increase crime (columns 1-4). The coefficient of rainfall deviation square remains highly consistent across these specifications. Population density yields a negative correlation with property crime, suggesting a more moderate response to weather fluctuations in areas that are less densely populated. Road density yields a positive coefficient but it is statistically insignificant, not allowing for further interpretation. Police staff per capita yields a strongly negative correlation with property crime, implying that more policing lowers the rate of offenses and crime (see also Roeder et al., 2015).

[16] For comparison purposes, Table A-8 in the Appendix presents the results for violent crime following an identical structure.

We also test for the symmetricity of the effect by including the 'positive rainfall shock' and 'negative rainfall shock' variables into the analysis. A standard deviation increase in rainfall increased property crimes by 17.7% and similarly, a standard deviation decrease in rainfall increased property crimes by 8.3%. This result is in line with previous findings by Papaioannou (2016) for Nigeria and Papaioannou & de Haas (2015) for colonial British Africa. A possible explanation is that in years of excessive rainfall farmers would lose their entire harvest in a relatively shorter time, whereas in years of drought farmers could hope for late rains. In the former case, the certainty of a failed harvest more rapidly reduces the opportunity cost of crime. Another possible explanation is that in tropical regions with relatively abundant rainfall regimes, excessive precipitation causes flooding and acute surface run-offs which, in turn, hurt harvests considerably more.

Table 4. *Curvilinear Impact of Rainfall Shocks on Property Crime*

	Ln(Property crime)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rainfall deviation t	0.009	0.014	0.017	0.015				
	(0.010)	(0.015)	(0.017)	(0.018)				
Rainfall deviation squared t	0.053***	0.055***	0.051***	0.051***				
	(0.007)	(0.009)	(0.009)	(0.009)				
Positive rainfall shock t					0.176***	0.186***	0.172***	0.174***
					(0.028)	(0.022)	(0.025)	(0.030)
Negative rainfall shock t					0.081***	0.083***	0.068**	0.073**
					(0.029)	(0.031)	(0.035)	(0.036)
Ln(Population density)				-0.591**				-0.533*
				(0.294)				(0.303)
Ln(Road density)				0.165				0.163
				(0.175)				(0.171)
Ln(Police staff per capita)				-0.496***				-0.496***
				(0.128)				(0.136)
District & Year FE	N	Y	Y	Y	N	Y	Y	Y
District-specific effects (District dummy × Trend)	N	N	Y	Y	N	N	Y	Y
No. observations	576	576	576	576	576	576	576	576

Notes: *Significant at 10%, ** 5%, ***1%. Reported in parentheses are standard errors clustered at the district level. The dependent variable is the logarithm of the property crime variable expressed as 100.000 of the population. The estimated coefficients can be interpreted as percentage changes. District-specific effects indicate the interaction of each District dummy × Time trend.

4.5.2 Poverty & Property Crime: An Instrumental Variable Approach

We now proceed by identifying the income channel as the causal explanation that drives the underlying relationship between income shocks and property crime. We use *absolute rainfall deviation*$_{i,t}$ as an instrument to generate exogenous variation in food production. The rainfall instrument is reasonably strong (the F-statistic is 18.3 in column 3 of Table 5).

Table 5. *Rainfall Shocks* & *Food Production (First-stage)*

	Dependent variable: Food Production				
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	OLS
Absolute Rainfall Deviation *t*	-0.547***	-0.530***	-0.516***	-0.545***	-0.504***
	(0.084)	(0.086)	(0.084)	(0.096)	(0.083)
Absolute Rainfall Deviation *t - 1*				-0.067	
				(0.093)	
Absolute Rainfall Deviation *t - 2*				-0.074	
				(0.086)	
Absolute Rainfall Deviation *t + 1*					-0.022
					(0.065)
District & Year FE	Y	Y	Y	Y	Y
Controls	N	N	Y	Y	Y
District-specific effects (District dummy × Time trend)	N	Y	Y	Y	Y
No. observations	552	552	552	401	483

Notes: *Significant at 10%, **5%, ***1%. Reported in parentheses are standard errors clustered at the district level. The dependent variable is the standardized annual rice production (z-score). Controls include population density, road density and police per capita. District-specific effects indicate the interaction of each District dummy × Time trend. The F-statistic of our preferred specification (column 3) is 18.3.

This way it is argued that loss of income from agriculture in year *t* causally predicts higher levels of property crime in year *t* (while having no effect on violent crime). As shown in Table 5, the first-stage relationship between rainfall and food production is strongly negative: current (and not lead or lagged) rainfall deviation is significantly related to padi rice yields at 99 percent confidence (Table 5, column 1), and this relationship is robust to the inclusion: of time dummies, fixed effects and district-specific time trends (column 2), of additional controls (column 3) and of lagged rainfall deviation from the previous two years (*t-1* & *t-2*) (column 4). As an identification check, we estimate a "false experiment" specification in which lead rainfall deviation (*t+1*) is included as an additional explanatory variable. We find that the coefficient estimate is indeed near zero (column 5).

The second-stage equation estimates the impact of loss of income on the incidence of property crime by performing a two-stage least square estimation (IV-2SLS):

$$Ln(Property\ crime)_{i,t} = \beta_0 + \beta_1\ FoodProduction_{i,t}\ [\text{IV: } AbsoluteRainfalldeviation_{i,t}] + \delta Z'_{i,t} + v_i + \mu_t + (District\ dummy \times Year)_{i,t} + \varepsilon_{i,t} \quad (2)$$

The estimated coefficient of food production on property crime is -0.085 (or -8.5%) in the OLS specification with time and fixed effects (Table 6, regression 1) and -0.088 (-8.8%) when district-specific effects and controls are included (regression 2). Both estimated coefficients are statistically significant at 99% confidence. The IV-2SLS estimates also indicate a negative and significant association between poverty and crime. A one standard deviation increase in rice production decreases property crime by 21.2% (regression 3). Notice that this is about double the magnitude of the analogous OLS estimate (-8.5%), suggesting that the bias in the OLS regression is large and underestimates the effect of poverty on crime.[17] In other words, simple correlation between rice production and crime may appear misleading, highlighting the value of the IV approach we develop.

We next estimate the impact of loss of income on vagrancy arrests. Under the British colonial rule, begging was illegal and destitute people ended up in police reports. Even though vagrancy can hardly be characterized as crime, it could serve as a suitable proxy for dire poverty. We expect vagrancy to yield a similar robust correlation as property crime. Indeed, the results show that the relationship between food production and vagrancy is negative and highly significant, which suggests that depressed incomes were a major determinant of poverty. One standard deviation decrease in rice production increases the amount of arrested

[17] In addition, there can be classical measurement error, which would lead to attenuation bias.

vagrants by 13.8% (regression 6). Table A-6 reports the IV-2SLS results on violent crime. All the estimated coefficients are nearly zero.

Table 6. *Baseline IV-2SLS Results: Poverty & Crime*

	Ln(Property crime)				Ln(Vagrancy)	
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	IV-2SLS	IV-2SLS	OLS	IV-2SLS
Food production *t*	-0.085***	-0.088***	-0.212***	-0.198***	-0.047***	-0.138***
	(0.010)	(0.010)	(0.032)	(0.032)	(0.013)	(0.047)
District & Year FE	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	Y	Y
District-specific effects (District dummy × Trend)	N	Y	N	Y	Y	Y
No. observations	552	552	510	510	339	303

Notes: *Significant at 10%, **5%, ***1%. Reported in parentheses are robust standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicate the interaction of each District dummy × Time trend. The instrumental variable is rainfall deviation at year *t*. Vagrancy statistics were not available for the whole sample.

4.5.3 Heterogeneous Effects

To further enhance our understanding on the role played by agricultural income in driving the relationship between rainfall shocks and property crime, we explore heterogeneous compliance in treatment effects across districts, conditional on several contextual factors including market access, commercial agriculture, percentage of the population working in rice agriculture, public spending and districts being net rice importers or exporters. Table 7 presents the results for different sub-samples, reporting a wide range of compliers. This exercise is similar to Dell (2012) and Fenske & Kala (2015). Column 1 reports the baseline second stage relationship from the full sample, reproducing Column 3 of Table 6 for comparison purposes. Column 2 presents the results for districts that were net rice importers and Column 3 for net rice exporters. While both yield a statistically significant correlation with property crime, the difference between the two coefficients is not statistically significant (p-value = 0.231), suggesting that this relationship was not particularly influenced by whether a district was rice importer or exporter.

Column 4 limits the sample to districts that showed a lower percentage of padi-rice cultivation than the median district, and Column 5 limits the sample to districts that showed a higher percentage of padi-rice than the median. Both coefficients are statistically different from zero, and they are not statistically distinguishable from each other (p-value= 0.183). Despite the slightly higher coefficient of districts with a lower percentage of padi-rice production than the median district (coeff.= -0.181, s.e.= 0.028), the results suggest that the vast majority of households suffer a loss in income when food production is low, regardless of the total volume of per capita rice produced in that particular district.[18] This finding is in line with Iyer & Topalova (2014), who find that rainfall shocks in India decrease average consumption across the full range of the income distribution, impacting all segments and production classes of society.

Columns 6 and 7 divide the sample by whether the district was exporting considerable volumes of cash crops (mainly rubber, coconut, tea and cocoa) than the median district. The correlation between food production and property crime is statistically significant in both samples, and it is substantially larger in the less commercial agricultural sample (coeff.= -0.312, s.e.= 0.096) than in the more commercialized sample (coeff.= -0.157, s.e.= 0.088). Moving from the more commercialized districts to the less commercialized ones, the relationship become more pronounced and property crime increases by almost half. We argue that the widening gap seen in the estimated coefficients is due to the lack of economic diversification. It seems likely that agricultural commercialization and crop diversification acted as an insurance mechanism to local households by generating an alternative source of income. This result is in line with that of Papaioannou and de Haas (2015) for colonial British Africa and Burgess & Donaldson (2012) for colonial India; both effectively arguing that crop diversification and openness to trade mitigated the adverse effects of weather shocks.

[18] In results not reported, we find that vagrancy rates exhibit a similar outcome for both high and low percentage of per capita padi-rice cultivation. The effect was statistically significant in both sub-samples, but it was not statistically distinguishable from each other (p-value= 0.344).

Table 7. *Heterogeneous Effects: Compliers*

Dependent variable: Ln(Property crime)							
		Importer	Exporter	Less	More	Less	More
	Baseline	Rice		Rice Agriculture (%)		Cash Crops	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS
Food production *t*	-0.198***	-0.178***	-0.216***	-0.181***	-0.231***	-0.312***	-0.157**
	(0.032)	(0.031)	(0.041)	(0.029)	(0.087)	(0.096)	(0.088)
District & Year FE	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y
District-specific effects (District dummy × Time Trend)	Y	Y	Y	Y	Y	Y	Y
No. observations	510	180	330	246	264	270	240

Dependent variable: Ln(Property crime)							
		Low	High	Low	High	Low	High
	Baseline	Market Access		Public Expenditure		Rainfall CV	
	(1)	(8)	(9)	(10)	(11)	(12)	(13)
	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS
Food production *t*	-0.198***	-0.255***	-0.143**	-0.187***	-0.211***	-0.212***	-0.168***
	(0.032)	(0.060)	(0.078)	(0.038)	(0.041)	(0.045)	(0.052)
District & Year FE	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y
District-specific effects (District dummy × Time Trend)	Y	Y	Y	Y	Y	Y	Y
No. observations	510	290	220	280	230	230	280

Next, we hypothesize that districts possessing less infrastructural density experienced higher transportation barriers and costs and were more difficult to reach by potential food relief programs. Columns 8 and 9 divide the sample by whether the district had less barriers to market access than the median district. We proxy market access with infrastructural density. We expect districts with relatively more dense road network to be less susceptible to shocks, since high road density facilitates inter-regional and international trade. The correlation between food production and property crime is statistically significant in both samples but is substantially larger in the districts with higher infrastructural density. The two coefficients are statistically distinguishable from each other (p-value = 0.038). The greater responsiveness of property crimes to food shocks in more isolated districts is a reflection of the scarcity of alternative income opportunities from trade. Columns 10 and 11 divide the sample by whether a district had a higher level of public expenditure than the median district. The reasonable assumption is that districts with a relatively higher budget could intervene and invest in years of agricultural loss, hence the poverty-crime effect would be attenuated. Nevertheless, we find this not to be the case. The difference between the two samples is insignificant (p-value= 0.311).

Lastly, Columns 12 and 13 tackle potential concerns related to the likelihood of some districts receiving more rainfall shocks than the median district. To achieve that, we have transformed our rainfall data following the coefficient of variation (CV) formula, also known as relative standard deviation (RSD). This is a standardized measure of rainfall dispersion which is expressed as a percentage. It is defined as the ratio of the standard deviation σ_i to the mean μ of each district i. The values for CV rainfall range from 0.0919 to 0.2574. The sample is split by whether the district is more likely to face a rainfall shock than the median district. Our results show that while both are statistically different from zero, they are not statistically distinguishable from each other (p-value = 0.167).

4.5.4 Robustness Checks

We now check the robustness of the preferred IV-2SLS estimates as reported in Table 6. First, Table A-2, shows that replacing rainfall deviation obtained from meteorological stations with an alternative measure of rainfall, based on the Matsuura and Wilmott (2009) world rainfall database (0.5 x 0.5 grid), gives nearly identical results. Second, account is taken of widening differences across countries as well as heterogeneity during the 30 year horizon of this study and Table A-3, presents the IV-2SLS results of standard errors clustered at the country level, year level as well as two-way clustered at both country and year level.

Third, we examine the sensitivity of the main estimates to the use of alternative instrumental specifications. Column 1 of Table A-4 reports estimates using rainfall in the lagged year *t-1* and two years earlier *t-2* as instrumental variables. Similarly, as an identification check, we estimate a "false experiment" specification in which leads of rainfall deviation in year *t+1* and *t+2* are included as instrumental variables, and find that the coefficient estimate is indeed near zero (column 2). As an additional falsification test, we re-estimate our main IV-2SLS results by using temperature shocks as an instrumental variable (column 3). These checks provide additional validation to our empirical strategy.

Table A-5 reports the IV-2SLS estimates for each individual category of crime, and Table A-6 for violent crimes. In results not reported, we obtain statistically identical results, if we use standardized beta coefficients (z-scores) for transforming the main dependent variables. Thus, the IV-2SLS results are not specific to the choice of functional form. Lastly, to ensure that our results are not driven by spatial spillovers, since rainfall patterns could be spatially correlated, we control for spatial and serial correlation using methods suggested by Hoechle (2007). The results remain largely unchanged.

4.5.5 Potential Violations of the Exclusion Restriction

While it is intuitively plausible that the rainfall instruments are exogenous, we have to evaluate whether they satisfy the exclusion restriction–i.e. weather shocks should affect property crime only through falling agricultural income. We acknowledge the possibility that economic channels (either direct or indirect ones) other than annual rice production may affect crime in the aftermath of adverse rainfall shocks. One possible violation of the exclusion restriction may occur in the case when rainfall shocks directly impact on crime; in an extreme rainfall scenario, flooded roads for instance, may reduce criminals' likelihood of stealing due to transportation difficulties or may hamper police capacity to report crimes. If such channels are present, IV estimates could misattribute the direct effects of rainfall to poverty. Note though that such alternative explanations do not pose a serious threat to the estimation, since excessive rainfall is associated with more (not less) crime in the reduced-form regression (coeff. +0.172 in Table 4 column 7). Thus to the extent that a bias exists, our estimates would be lower bounds of the true impact of poverty on property crime.

Another possible concern is that the colonial states may have intervened by investing more in places with extreme poverty. If extreme poverty was declining, and property crimes were to a large extent driven by poverty, one might expect the impact of food production on crime to decrease over time. To test for such a concern, we include interaction terms between food production and a time trend, which we instrument with interactions between rainfall shocks and a time trend. However, we do not find support for the claim that the effect of poverty on property crime attenuated during the study period (results not reported).

Another possible channel is psychological, as rainfall may affect people's moods by making them more or less inclined to commit a crime. A clear candidate here is high temperature shocks which have been found to cause elevated aggression (Anderson 1989) and violent crimes (Ranson 2014). We find that temperature shocks are not positively or negatively associated with rice yields (Table A-7, column 1) nor with property crimes (column 2). However, consistent with the relevant literature (Anderson et al. 2000; Iyer & Topalova 2014; Blakeslee

& Fishman 2015), we find that temperature shocks are associated with 4.3% more violent crimes (column 3).

4.6 Conclusion

This article suggests that income shocks, and by extension poverty, are a key underlying cause of property crime in British colonial Asia. We estimate the causal effect of reduced rice production on crime using rainfall variation as an instrumental variable for rice production, and find that the effect of abrupt income shocks on property crime is indeed considerably large. A one standard deviation decrease in annual rice production is found to increase property crime by 21.2%. This effect is considerably higher in magnitude to accumulated evidence from other studies reviewed by Hsiang et al. (2013). One explanation for such a large effect may arise from the fact that we are dealing with a highly agrarian/non-industrial part of the world, where the vast majority of the total income is derived from agricultural practises , and where urban labour was limited. Another possible explanation has to do with the institutional context in which this study is embedded and the limited attention the colonial governments paid to local food production. Lastly, it may has to do with the substantially low living standards prevailing among rural communities at the time, where nutritional intakes for the mass of the population did not improve, and as a result mortality rates were high.

With the use of rainfall as an instrumental variable for padi-rice production, this article also addresses a methodological challenge; i.e. endogeneity and reverse causality, since the effect between poverty and crime is larger than simple OLS estimates would suggest (8.5%), thus highlighting the importance of using instrumental variable methods. Additionally, we show that a one standard deviation decrease in rice production increases begging and vagrancy by 14.1%. This finding strongly suggests that rice production was a key determinant of absolute poverty during this period, which in turn led to increased crime.

Although no effect was found between income shocks and violent crime, the results confirm a direct extra-economic channel between high temperature and violent behaviour. A one standard deviation increase in temperature is associated with 4.3% increase in violent crime. This serves as an important validation of the empirical strategy and highlights the importance of looking beyond aggregate crime measures in this climate-crime literature, since they may obscure heterogeneous patterns across crime categories.

The Asian renaissance of the second half of the twentieth century has been primarily associated with substantial gains in agricultural output and productivity. However, that was not always the case as there were fears in the 1950s and the early 1960s that the tropical Asian rice-based economy would be experiencing massive famine and starvation because the region had already reached its cultivation frontier (Otsuka & Larson, 2014). Prior to the Green Revolution (beginning in the 1960s), food shortages and famines were considered a typical Asian phenomenon (O' Grada, 2009). Nutritional intakes for the mass of the population did not improve, and mortality rates were considerably high in that part of the world (Booth, 2012). The results contained herein add supporting evidence to this idea, since it is found that falling agricultural incomes, and by extension rural poverty, primarily affected the categories of crime that alleviated economic distress.

Beyond improving our understanding on local conditions of early twentieth century South and South-East Asian states, the implication of this study may be important from a public policy perspective in contemporary developing countries. Taken together, the results of this research securely support the idea of improved high-yield weather-resistant grains and investments in irrigation and drainage technology. The promise of a stable annual harvest would potentially eliminate much of the adverse crime-induced poverty traps, as well as the subsequent unfolding vicious cycle of crime and further disruptions to human welfare (Bourguignon, 2000). Unfortunately, climate change continues and will bring about more erratic weather events, adversely affecting the poorest and economically vulnerable smallholder farmers the most. A key policy priority should therefore be to aim at long-term protection of the most vulnerable and precarious farmers of the global south.

Appendix A

Table A-1. *Correlation among Crime Measures*

	Property crime	Violent crime	Theft	Cattle-raiding	Assault	Homicide	Vagrancy
Ln(Property crime)	1.000						
Ln(Violent crime)	0.117	1.000					
Ln(Theft)	0.824*	0.097	1.000				
Ln(Cattle-raiding)	0.628*	-0.018	0.409*	1.000			
Ln(Assault)	0.330	0.772*	0.267	0.367	1.000		
Ln(Homicides)	0.524	0.456*	0.240	0.199	0.371*	1.000	
Ln(Vagrancy)	0.364*	0.085	0.306*	0.312*	0.509*	0.476*	1.000

Notes: Correlation coefficients are reported. * Denotes significant at 5%. All crime measures are expressed as the logarithm of per 100,000 of the population.

Table A-2. *Poverty & Property Crime: using rainfall grids*

	Ln(Property crime)				Ln(Vagrancy)	
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	IV-2SLS	IV-2SLS	OLS	IV-2SLS
Food production *t*	-0.085***	-0.088***	-0.168***	-0.179***	-0.037**	-0.269**
	(0.010)	(0.010)	(0.046)	(0.053)	(0.013)	(0.110)
District & Year FE	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	Y	Y
District-specific effects (District dummy × Trend)	N	Y	N	Y	Y	Y
No. observations	552	552	531	531	339	303

Notes: *Significant at 10%, **5%, ***1%. Sample period: 1910–1939. Reported in parentheses are robust standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicates the interaction of each District dummy × Trend. The instrumental variables are rainfall deviation at year *t* and in the lagged year (*t-1*).

Table A-3. *Clustering Standard Errors at Different Levels*

	Dependent variable: Ln(Property crime)			
	(1)	(2)	(3)	(4)
	IV-2SLS	IV-2SLS	IV-2SLS	IV-2SLS
Food Production *t*	-0.202	-0.212	-0.206	-0.198
	(0.0302)	(0.0327)	(0.0328)	(0.0326)
		<0.0375>	<0.0.378>	<0.0393>
		[0.0358]	[0.0371]	[0.0413]
	Dependent variable: Ln(Vagrancy)			
Food Production *t*	-0.151	-0.145	-0.116	-0.138
	(0.0483)	(0.0501)	(0.0462)	(0.0471)
		<0.0485>	<0.0300>	<0.0369>
		[0.0628]	[0.0460]	[0.0507]
District & Year FE	N	Y	Y	Y
Controls	N	N	Y	N
District-specific effects (unobservable x year)	N	N	N	Y

Notes. The specifications and the estimated coefficients in this Table are the same as in Table 6. The standard errors in columns 2–4 are clustered at the district level (in parentheses), the country level (in angle brackets) as well as two-way clustered both the country and the year level (in square brackets).

Table A-4. *Poverty & Property Crime: using Lags and Leads Rainfall as Instruments*

	Ln(Property crime)		
	(1)	(2)	(3)
	IV-2SLS	IV-2SLS	IV-2SLS
Food production t [IV: Rainfall $t-1$ & $t-2$]	-0.525		
	(0.385)		
Food production t [IV: Rainfall $t+1$ & $t+2$]		-0.332	
		(0.451)	
Food production t [IV: Temperature t]			0.261
			(0.389)
District & Year FE	Y	Y	Y
Controls	Y	Y	Y
District-specific effects (District dummy × Trend)	Y	Y	Y
No. observations	366	358	552

Notes: *Significant at 10%, **5%, ***1%. Sample period: 1910–1939. Reported in parentheses are robust standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicate the interaction of each District dummy × Trend. Column 1: the instrumental variables are rainfall deviation in the lagged year ($t-1$), and two years earlier ($t-2$). Column 2: the instrumental variables are rainfall deviation in the lead year ($t+1$), and two years later ($t+2$). Column 3: the instrumental variable is temperature deviation in year t.

Table A-5. *Poverty & Property Crime: Specific Crime Categories*

	Ln(Theft)				Ln(Cattle-raiding)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	IV-2SLS	IV-2SLS	OLS	OLS	IV-2SLS	IV-2SLS
Food production *t*	-0.082***	-0.077***	-0.222***	-0.208***	-0.096***	-0.077***	-0.199***	-0.176***
	(0.010)	(0.010)	(0.032)	(0.032)	(0.010)	(0.009)	(0.035)	(0.039)
District & Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	N	Y	N	Y
District-specific effects (District dummy × Trend)	N	Y	N	Y	N	Y	N	Y
No. observations	552	552	521	521	417	417	385	385

Notes: *Significant at 10%, **5%, ***1%. Sample period: 1910–1939. Reported in parentheses are robust standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicates the interaction of each District dummy × Trend. The instrumental variables are rainfall deviation at year *t* and in the lagged year (*t-1*).

Table A-6. *Poverty & Violent Crime*

	Ln(Violent crime)			
	(1) OLS	(2) OLS	(3) IV-2SLS	(4) IV-2SLS
Food production *t*	-0.056	-0.001	-0.007	0.002
	(0.048)	(0.059)	(0.176)	(0.189)
District & Year FE	Y	Y	Y	Y
Controls	N	Y	N	Y
District-specific effects (District dummy × Trend)	N	Y	N	Y
No. observations	600	600	575	575

Notes: *Significant at 10%, **5%, ***1%. Reported in parentheses are robust standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicates the interaction of each District dummy × Trend. The instrumental variables are rainfall deviation at year *t* and in the lagged year (*t-1*).

Table A-7. *Temperature Shocks & Crime*

	Food Production	Ln(Property Crime)	Ln(Violent Crime)
	(1) OLS	(2) OLS	(3) OLS
Temperature deviation *t*	0.070	0.035	0.043**
	(0.084)	(0.025)	(0.018)
District & Year FE	Y	Y	Y
Controls	Y	Y	Y
District-specific effects (District dummy × Trend)	Y	Y	Y
No. observations	552	576	600

Notes: *Significant at 10%, **5%, ***1%. Reported in parentheses are robust standard errors clustered at the district level. Controls include population density, road density and police per capita. District-specific effects indicates the interaction of each District dummy × Trend.

Table A-8. *Rainfall Shocks & Violent Crime*

	Ln(Violent crime)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rainfall deviation *t*	0.033	0.042	0.021	0.034				
	(0.041)	(0.044)	(0.019)	(0.040)				
Rainfall deviation squared *t*	0.055	0.070	0.088	0.091				
	(0.037)	(0.063)	(0.071)	(0.083)				
Positive rainfall shock *t*					0.292	0.249	0.148	0.145
					(0.207)	(0.238)	(0.164)	(0.171)
Negative rainfall shock *t*					0.177	0.019	-0.005	-0.041
					(0.150)	(0.020)	(0.131)	(0.147)
Ln(Population density)				-0.389**				-0.344**
				(0.188)				(0.193)
Ln(Road density)				0.547*				0.128
				(0.253)				(0.171)
Ln(Police staff per capita)				-0.367**				-0.382**
				(0.175)				(0.201)
District & Year FE	N	Y	Y	Y	N	Y	Y	Y
District-specific effects (*unobservable* × Time Trend)	N	N	Y	Y	N	N	Y	Y
No. observations	576	576	576	576	576	576	576	576

Notes: *Significant at 10%, ** 5%, ***1%. Sample period: 1910–1939. OLS-FE. Reported in parentheses are standard errors clustered at the district level. The dependent variable is the logarithm of the violent crime variable expressed as 100.000 of the population. The estimated coefficients can be interpreted as percentage changes. District-specific effects indicate the interaction of each District dummy × Trend.

Historical Sources

Statistical Yearbooks & Government Reports

All documents were retrieved from The National Archives, London. Government Printing Office: various issues, reported in alphabetical order.

Brunei Annual Report: Department code: CO 842, Series number: 1–2.

Ceylon Administration Report: Department code: CO 57, Series number: 176–258.

______________Blue Book: Department code: CO 59, Series number: 120-152.

Federated Malay States Administration Report: Department code: CO 576, Series number: 5–65.

______________Blue Book: Department code: CO 575, Series number: 1-37.

______________Provincial Report: Department code: CO 435/437/438/439, Series number:1-4.

Johore Annual Report: Department code: CO 715, Series number: 1-5.

Kedah & Perlis Annual Report: Department code: CO 716, Series number: 1-4.

Kelantan Annual Report: Department code: CO 827, Series number: 1-2.

North Borneo (Sabbah) Annual Report: Department code: CO 648, Series number: 1-22.

______________Blue Book: Department code: CO 966, Series number: 1.

Straits Settlements Annual Report: Department code: CO 275, Series number: 84-151.

______________Blue Book: Department code: CO 277, Series number: 53-91.

Trengganu Annual Report: Department code: CO 840, Series number: 1-2.

References

Anderson, C. A. (1989). Temperature and aggression: ubiquitous effects of heat on occurrence of human violence. *Psychological bulletin*, *106*(1), 74.

Anderson, C. A., Anderson, K. B., Dorr, N., De Neve, K. M., & Flanagan, M. (2000). Temperature and aggression. *Advances in experimental social psychology*, 32, 63-129.

Anderson, R. W., Johnson, N. D., & Koyama, M. (2015). Jewish Persecutions and Weather Shocks: 1100-1800. *The Economic Journal.*

Bai, Y., & Kung, J. K. S. (2011). Climate shocks and Sino-nomadic conflict. *Review of Economics and Statistics*, *93*(3), 970-981.

Becker, G. S. (1974). Crime and punishment: An economic approach. In *Essays in the Economics of Crime and Punishment* (pp. 1-54). NBER.

Bignon, V., Caroli, E., & Galbiati, R. (2016). Stealing to Survive? Crime and Income Shocks in Nineteenth Century France. *The Economic Journal*.

Blakeslee, D., & Fishman, R. (2014). Weather shocks, crime, and agriculture: evidence from India. *Social Science Research Network*.

Blau, J. R., & Blau, P. M. (1982). The cost of inequality: Metropolitan structure and violent crime. *American Sociological Review*, 114-129.

Booth, A. (1999). Initial conditions and miraculous growth: why is South East Asia different from Taiwan and South Korea?. *World Development*, *27*(2), 301-321.

Booth, A. (2012). Measuring living standards in different colonial systems: some evidence from South East Asia, 1900–1942. *Modern Asian Studies*, *46*(05), 1145-1181.

Bourguignon, F. (2000, December). Crime, violence and inequitable development. In *Annual World Bank Conference on Development Economics 1999* (pp. 199-220).

Bray, F. (1994). *The rice economies: technology and development in Asian societies*. University of California Press.

Brückner, M., & Ciccone, A. (2011). Rain and the democratic window of opportunity. *Econometrica*, *79*(3), 923-947.

Bruton, H. J. (1992). *The political economy of poverty, equity, and growth: Sri Lanka and Malaysia*. Oxford University Press.

Buhaug, H., Nordkvelle, J., Bernauer, T., Böhmelt, T., Brzoska, M., Busby, J. W., ... & Goldstone, J. A. (2014). One effect to rule them all? A comment on climate and conflict. *Climatic Change*, *127*(3-4), 391-397.

Burke, M., Dykema, J., Lobell, D. B., Miguel, E., & Satyanath, S. (2015). Incorporating climate uncertainty into estimates of climate change impacts. *Review of Economics and Statistics*, *97*(2), 461-471.

Butcher, G. J. (1979). *The British in Malaya, 1880-1941*. Oxford University Press.

Christian, C., & Fenske, J. (2015). *Economic shocks and unrest in French West Africa* (No. 2015-01). Centre for the Study of African Economies, University of Oxford.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature*, 52(3), 740-798.

Dell, M. (2012). Path dependence in development: Evidence from the Mexican Revolution. *Harvard University, mimeograph.*

Drabble, J. H. (1974). *Rubber in Malaya 1876-1922: the genesis of the industry*. Oxford University Press.

Elson, R. E. (1997). *The end of the peasantry in Southeast Asia: A social and economic history of peasant livelihood, 1800-1990s*. Springer.

Fajnzylber, P., Lederman, D., & Loayza, N. (2002). What causes violent crime?. *European Economic Review*, *46*(7), 1323-1357.

Farmer, B. H. (1977). *Pioneer peasant colonization in Ceylon*. Oxford University Press.

Fenske, J., & Kala, N. (2015). Climate and the slave trade. *Journal of Development Economics*, *112*, 19-32.

Fjelde, H., & von Uexkull, N. (2012). Climate triggers: Rainfall anomalies, vulnerability and communal conflict in sub-Saharan Africa. *Political Geography*,*31*(7), 444-453.

González, F., & Miguel, E. (2015). War and local collective action in Sierra Leone: A comment on the use of coefficient stability approaches. *Journal of Public Economics*, 128, 30-33.

Grossman, H. I. (1991). A general equilibrium model of insurrections. *The American Economic Review*, 912-921.Oxford University Press.

Herbst, J. (2000). *States and power in Africa: Comparative lessons in authority and control.* Princeton University Press.

Hill, R. D. (2012). *Rice in Malaya: a study in historical geography*. NUS Press.

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *Stata Journal*, *7*(3), 281.

Hsiang, S. M., Burke, M., & Miguel, E. (2013). Quantifying the influence of climate on human conflict. *Science*, *341*(6151), 1235367.

Iyer, L., & Topalova, P. B. (2014). Poverty and crime: evidence from rainfall and trade shocks in India. *Harvard Business School BGIE Unit Working Paper*, (14-067).

Jia, R. (2014). Weather shocks, sweet potatoes and peasant revolts in historical China. *The Economic Journal*, *124*(575), 92-118.

Kelly, M. (2000). Inequality and crime. *Review of economics and Statistics*, *82*(4), 530-539.

Klomp, J., & Bulte, E. (2013). Climate change, weather shocks, and violent conflict: a critical look at the evidence. *Agricultural Economics*, *44*(s1), 63-78.

Lange, M. K. (2004). British colonial legacies and political development. *World Development*, *32*(6), 905-922.

Lim, T. G. (1976). *Origins of a colonial economy: land and agriculture in Perak, 1874-1879*. Penerbit University Sains Malaysia: distributed by Federal Publications.

Matsuura, K., & Willmott, C. J. (2009). Terrestrial precipitation: 1900-2010 gridded monthly time series.

Mehlum, H., Miguel, E., & Torvik, R. (2006). Poverty and crime in 19th century Germany. *Journal of Urban Economics*, *59*(3), 370-388.

Miguel, E. (2005). Poverty and witch killing. *The Review of Economic Studies*,*72*(4), 1153-1172.

Miguel, E., Satyanath, S., & Sergenti, E. (2004). Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy*,*112*(4), 725-753.

Miguel, E. (2005). Poverty and witch killing. *The Review of Economic Studies*, *72*(4), 1153-1172.

Mills, L. A. (1964). *Ceylon under British rule, 1795-1932*. Routledge.

Oster, E. (2014). Unobservable selection and coefficient stability: Theory and evidence. University of Chicago Booth School of Business Working Paper.

Papaioannou, K. J. (2016). Climate shocks and conflict: Evidence from colonial Nigeria. *Political Geography*, *50*, 33-47.

Papaioannou, K. J., & De Haas, M. (2015). Climate Shocks Cash Crops and Resilience: Evidence from Colonial Tropical Africa. *World Development*.

Parmer, N. J. (1960). *Colonial labour policy and administration*. J.J.Augustin, New York.

Ranson, M. (2014). Crime, weather, and climate change. *Journal of environmental economics and management*, *67*(3), 274-302.

Sarsons, H. (2015). Rainfall and conflict: A cautionary tale. *Journal of Development Economics*, *115*, 62-72.

Seter, H. (2016). Connecting climate variability and conflict: Implications for empirical testing. *Political Geography*, *53*, 1-9.

Tregonning, K. G. (1965). *A History of Modern Sabah (North Borneo, 1881-1963).* University of Singapore.

Wade, R. (1990). *Governing the market: Economic theory and the role of government in East Asian industrialization*. Princeton University Press.

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CHAPTER 5

Rainfall Patterns & Human Settlement in Tropical Africa & Asia Compared:

Did African Farmers Face Greater Insecurity?

Abstract

We explore a new dataset of annual and monthly district-level rainfall patterns to assess the longstanding idea that climatological conditions were more conducive to the development of dense rural populations in Asia than in Africa. We test whether there existed significant cross-regional differences in both the frequency and intensity of rainfall shocks (i.e. annual mean deviations exceeding one standard deviation). Our results confirm that rainfall shocks in tropical Africa were both more frequent and more severe. Second, we test the separate effects of precipitation *levels* and *variability* on district-level population densities from colonial population censuses. We hypothesize that higher mean levels of precipitation facilitate agricultural intensification and human settlement, while unpredictability of rainfall has the opposite effect. Controlling for average rainfall levels, we indeed find a strong negative effect of rainfall variation on population densities. This study thus lends further support to a wide literature arguing that the ecological conditions of agricultural intensification were more challenging in the African than in the Asian tropics.

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5.1 Introduction

Environmental conditions for sedentary agriculture have been a major determinant of the spatial distribution of the human species throughout recorded human history. Millennia ago, the world's prime peasant-based civilizations emerged in major river delta's with abundant access to fresh water or in mountainous terrains where differences in altitude and associated rainfall patterns allowed for highly diverse cropping systems in a relatively confined geographical area. Of course, access to fresh water –be it through regular precipitation or stored in lakes and rivers– wasn't all that mattered for the settlement and expansion of historical populations. The spread of human and animal diseases, the location of transportation networks and trade routes, and the presence of sub-soil deposits all played their part. Moreover, changes in agricultural and transportation technology allowed some sparsely inhabited regions to become more densely settled, while degrading environmental conditions had opposite effects in some former high density areas. Yet, despite long-term ecological and historical dynamics, the spatial connections between climate, agricultural development and human settlement are still visible at present (Diamond, 1997).

Adverse climatological conditions have been an oft-mentioned cause for disappointing productivity growth in African agriculture, and an important factor in explaining low historical densities of population as well as persistent poverty (Gallup et al., 1999; Sachs & Warner, 1997). Even though climates have varied over the past millennia, considerable parts of Africa such as the Sahara, parts of the Sahel, the Kalahari and parts of the East African lowlands have long been too arid to support agriculture (Mainguet, 1999; Strahler & Strahler, 1992). Recent global warming seems to have compounding disadvantageous effects on conditions for agricultural production, particularly in the Horn of Africa and the West African Sahel (Verschuren et al., 2000; Giannini et al., 2008). But there are also vast areas in sub-Saharan Africa with abundant rainfall supporting the cultivation of a wide range of food and cash-crops (Tosh, 1980, p. 80).

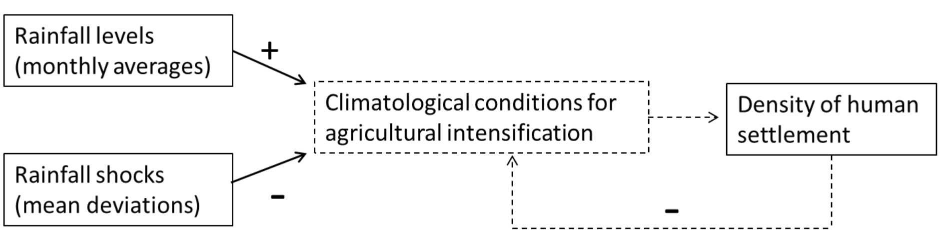
That rainfall patterns in tropical Africa may exhibit a greater degree of year-to-year variability than in other tropical areas has been given far less attention. Rainfall variability poses constraints to agricultural intensification and the growth of historical populations, even in areas where average precipitation levels are high enough to support the cultivation of a large range of crops. Under predictable rainfall regimes farmers can adapt their production strategies (e.g. by cropping drought resistant crops, practicing seasonal transhumance etc.), but when rains vary from year to year, such adaptations are more difficult to make.

Contrary to studies using contemporary climate data (Bloom et al., 1998; Gallup et al., 1999; Le Blanc & Perez, 2008), this study ventures into two questions of historical significance: has rainfall, on the whole, been more insecure and thus less predictable in tropical Africa than in tropical Asia? And if so, can this explain part of the difference in population densities that existed in both regions *before* the impact of modern medical and transportation technologies that created conditions for the major demographic boom and urbanization patterns of the post-1950 era?

We address these questions using historical rainfall data from colonial meteorological stations. We compiled a new dataset of annual and monthly rainfall levels collected from local weather stations set up by former colonial governments for 221 districts in tropical Africa (141) and Asia (80), parts of which were drawn from earlier studies by Papaioannou (2016; 2017) and Papaioannou and de Haas (2017). We refine existing measures of rainfall variability by distinguishing the overall variation in annual rainfall (expressed in coefficients of variation picking up deviations from the mean) from the *frequency* of rainfall shocks (defined as the no. of annual mean deviations exceeding one standard deviation) and the *intensity* of rainfall shocks (the average magnitude of the deviation). We use these measures to explore whether differences between tropical Africa and Asia were indeed significantly large to argue that African societies faced greater climatological insecurity.

As visualized in Figure 1, we are also interested in the impact of rainfall variability on population densities as a separate channel next to mean rainfall levels. Given the lack of reliable fine-grained data on agricultural output, we use district-level population densities taken from colonial population censuses (which we corrected for possible biases), as a proxy for conditions of agricultural intensification and associated stimuli to expanding human populations. In our regressions we control for several other factors that are likely to have impacted human settlement patterns, such as proximity to the coast, the presence of natural rivers and revealed mineral deposits. We find that, controlling for mean rainfall levels, rainfall variability indeed explains a substantial additional part of the variation in population densities across tropical Africa and Asia. Since we are unable to explore the causal channel in detail, and we also neglect possible negative feedback loops from increasing populations on agricultural production conditions, these tests only offer *indirect* support to the idea that climatological instability translated into higher cultivation risks and worsened long-term prospects of agricultural development.

Figure 1: *Schematic Overview of Second Hypothesis*



5.2 Tropical agriculture and environmental conditions

To explain the principles behind economic agglomeration and concentrations of human settlement, the new economic geography literature makes a critical distinction between *first* and *second nature geography* (Krugman, 1993). First nature geography refers to all environmental conditions such as climate, natural resources, natural transportation routes and so on, which jointly create advantages and disadvantages for economic production and related human reproduction. Second nature geography refers to the path dependence in locational choices of economic activity, by which historical accidents give rise to agglomeration effects because of the clustering of economic activities and agents in an earlier stage.

For tropical agriculture in Africa and Asia, where larger concentrations of people in cities were historically scarce, first order geography has arguably been more important in explaining the variation in population densities across space before modern technologies in medicine, transportation and food conservation established conditions for unprecedented rates of population growth and urbanization. Given the importance of these historical changes, it is helpful to further disentangle first order 'geography' into conditions that *directly* affect the reproduction of crops, livestock and human beings, from conditions that affect *the preservation and exchange* of agricultural commodities, and related possibilities of rural-urban labour specialization.

The idea that 'geography', in the broad sense of the term, has been less conducive to productivity growth in African agriculture than in other world regions has been expressed for centuries. Adam Smith in his *Wealth of Nations* alluded to the lack of opportunities for sea-bound trade and related division of labour, as Africa had none of the great water inlets such as the Baltic or Mediterranean seas to 'carry maritime commerce into the interior parts of that great continent' (1776, p. 30, quoted in Bloom et al. (1998), p. 237). Fernand Braudel also emphasized the importance of environmental conditions, or 'geography', in explaining divergent development paths between Europe and Africa in the *longue durée*. According to Braudel, Africa's lack of navigable waterways inhibited the commercialisation of subsistence economies (Braudel, 1995, p. 123). The view that prohibitive transportation costs resulting from a highly uneven spread of populations in large landlocked areas, have hampered long-term economic development in Africa is a recurrent theme in studies of African development (Collier, 2008; Gallup et al., 1999).

Food preservation is also more challenging in warmer climates, with modest seasonal variations in temperature. Gallup et al. (1999) show a strong adverse effect of tropical ecozones on the market value of agricultural output, which may lead to a productivity decrement of 30%-50% compared to temperate zone agriculture (p. 197). Without the possibility to store food in colder winters, the time between harvests and consumption of foodstuffs is shorter, limiting opportunities to transport food and produce for (distant) markets. It is also argued that farmers in tropical regions are confronted with lighter soils, facing rapid nutrient depletion in absence of artificial regeneration methods (Austin, 2008). Torrential tropical rains can cause the leaching of soil nutrients. But there is no direct reason to suppose that tropical soils and the complexities of food storage have put a larger constraint on agricultural development in the African tropics than in other tropical regions of the world.

Neither is it self-evident that tropical climates would inhibit agricultural development in all respects. Tropical areas are usually characterised by unique degrees of bio-diversity and there are many crops suitable for human consumption that grow in the tropics but cannot be grown in temperate areas. There is also no indication that conditions for crop domestication were less frequent in semi-tropical or tropical areas, although the evidence does seem to suggest that tropical regions with strong variation in elevations such as the Mexican cordillera, the Andean highlands and the Ethiopian highlands offered particular advantages for domestication efforts because of larger genetic diversity (Vavilov, 1951; Diamond, 1997).

It may indeed be the case, as Diamond (1997) has famously argued, that tropical areas pose additional barriers to the diffusion of domesticated plant and animal species, as well as related agricultural innovations (see also Olsson & Hibbs, 2005), because they require very high adaptive capacities. In particular the incidence of endemic tropical diseases has been notably worse in tropical Africa than elsewhere. Severe strains of trypanosomiasis have affected the reproduction of humans, horses and cattle, constraining the availability of animal draft power, animal manure and horseback transportation opportunities (Goody, 1980; Alsan, 2014; Frankema, 2015). Malaria and a number of other tropical diseases were also more severe in tropical Africa than elsewhere. Such endemic tropical diseases had a direct effect on human reproduction, but the indirect effects were substantial as well: it hampered the human capacity to tend soils, to herd cattle and to exchange agricultural commodities. That higher altitudes tended to have lower rates of human and animal infection also helps to explain why these areas became more densely populated than many of the lowland areas.

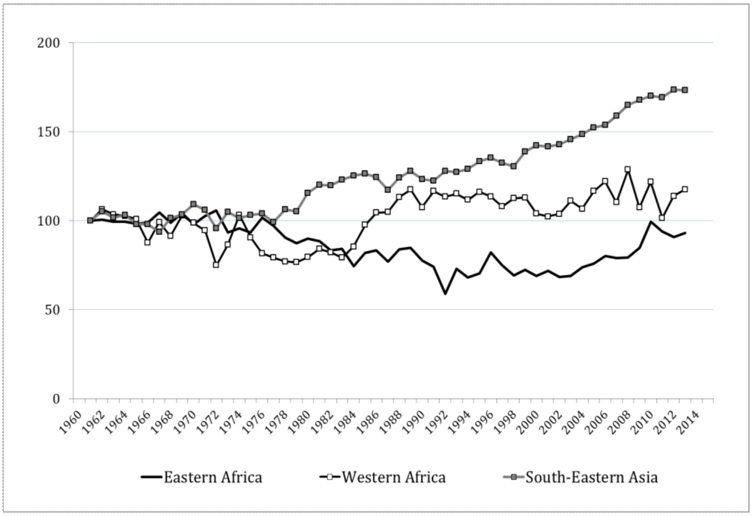
Technological innovations can erase barriers to agricultural productivity growth, but even then environmental factors remain important. The powerful combination of 'green revolution' technologies such as high-yielding varieties (HYVs) of rice, wheat, maize and chemical fertilizers, also require a regular supply of sunlight and fresh water to flourish. Areas with both abundant *and* predictable rains thus held a distinctive advantage over areas with low and/or variable precipitation. As the index series in Figure 2 show, gross per capita production of cereals diverged strongly under the influence of 'green revolution' technologies. The per capita output of cereals - especially paddy rice - in South-Eastern Asia had risen with ca. 75% in 2013 over 1961 levels. In Western Africa per capita production also rose, after a considerable setback in the 1970s and early 1980s, but not as impressive as in Southeast Asia, while in Eastern Africa per capita production levels have barely come back to the levels recorded in the 1960s and early 1970s.

Although differences in state capacity are often cited as a key factor in explaining why tropical Africa, contrary to large parts of tropical Asia, failed to herald a 'green revolution', it has also been widely acknowledged that the environmental odds were stacked against Sub-Saharan Africa in some important respects (Conway, 1998; Djurfeldt et al., 2005; Otsuka & Larson, 2013; Frankema, 2014; Booth et al., 2015). The composition of African soils appear to be more heterogeneous than elsewhere, which complicates re-generation efforts based on fertilizers (Smaling & Braun, 1996) and the vast ecological diversity and large variety in food production systems in tropical Africa has also prevented the use of 'silver bullet' HYVs, such as the IR8 rice and Norin 10 wheat varieties (Hayami et al., 1998; Hayami, 2000). Many scholars have argued that the vast ecological diversity of tropical Africa requires a different 'green evolution', a process of tailor-made interventions that generate lower economies of scale, and which will be more costly to effectuate (Conway, 1998; Otsuka & Larson, 2013, p. vi-vii; Frankema, 2014).

Sub-Saharan Africa is not just generally dryer, with larger arid areas than in East and Southern Asia, rainfall patterns also tend to be more erratic (Bloom et al., (1998), p. 222). The unpredictability of rainfall raises risks of harvest failures and thus affects cultivation choices (e.g. preference for drought resistant crops). Indirectly, these conditions also affect long-term investments in soil improvement, transportation networks and commercial infrastructures. In the past few decades the World Bank has composed drought indicators showing that a large group of tropical African countries experiences droughts more frequently and that there are significant differences in rainfall variability with other parts of the tropical world. Le Blanc and Perez (2008) have shown this statistically in a cross-country study using present-day climate data.

We will now take this research a step further by exploring the relationship between rainfall patterns and human settlement *using a more fine-grained dataset on a district level for a historical era that precedes large scale global carbon emissions and the major demographic boom in the developing world*, thus avoiding part of the noise inherent in studies using contemporary country-level data.

Figure 2: *Index series of gross per capita cereal production, 1961-2015 (1961 = 100)*



Source: FAOSTAT, Production statistics, data retrieved at 10-11-2016; http://faostat3.fao.org/download/Q/*/E

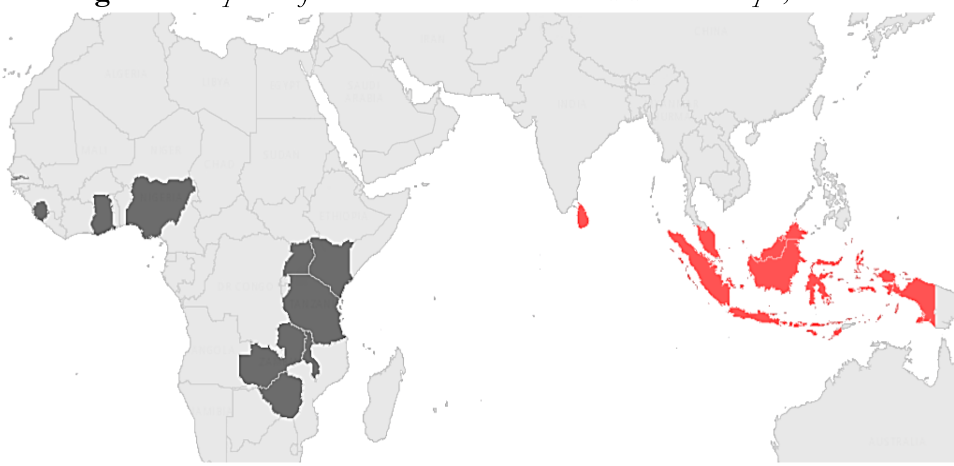
5.3 Data

5.3.1 Geographical demarcation

We obtained district level data on rainfall patterns and population densities for 221 districts in 10 Sub-Saharan African colonies (141 districts) and 7 Asian colonies (80 districts) for the period 1920-1940. The areas are presented in the map of Figure 3 and listed in Table A-1. The spatial coverage of this dataset is motivated by three considerations. First, all these African and Asian colonies/countries are located between the tropics of Cancer and Capricorn. Second, we selected areas in both West and East Africa to ensure that we capture sufficient intra-continental spatial variation to test our first hypothesis. Third, for reasons of data availability and data consistency, we focussed on former British colonies in which meteorological data were collected at weather stations with comparable high-frequency observations of rainfall and temperature.

Colonial administrations collected demographic data in decadal population censuses throughout the British empire. These census data, as we will highlight below, are certainly not fully reliable and many of the estimates require upward adjustment, since undercounting was common. That said, the census estimates definitely improved over time, and the estimates for the 1920s and 1930s have a (much) greater degree of accuracy than the censuses conducted in previous decades. Moreover, in view of the fact that most estimates for the 1950s and 1960s are more or less reliable, the error margins involved in adjusting the census figures through backward casting using default growth rates are relatively small (Manning, 2010; Frankema & Jerven, 2014). We made one exception to our focus on British colonial climate and population data by adding data for the Netherlands Indies (Indonesia), which exhibits a comparable degree of detail and accuracy.

Figure 3: *Tropical African* & *Asian countries included in our sample, c.1920*



Source: Created by the authors in ArcGIS.

5.3.2 Rainfall data

Our rainfall data were recorded at meteorological stations that were first introduced by British colonial governments in the late 19th century. The rainfall data were consistently reported throughout the period of interest and all districts included in our sample had at least one meteorological station within its borders. If districts had more than one weather station, we took the average of them. Our main measure of weather variability is the coefficient of variation (CV) of annual rainfall, also known as relative standard deviation (RSD). This is a standardized measure of rainfall dispersion which is expressed as a percentage. It is defined as the ratio of the standard deviation σ_i to the mean μ of each district i. The values for *CV rainfall* range from 0.094 to 0.435 (and from 0.034 to 0.156 in log form).

Since there are many ways to parameterize weather variability, we also transformed our data into two additional measures, capturing the *frequency* and *intensity* of rainfall deviations from the mean. We define a *rainfall shock* as a deviation from the long-term annual mean exceeding one standard deviation. Our *frequency of shocks* measure is then defined as the ratio of years with extreme rainfall variability exceeding one standard deviation from the long-term mean (i.e. 1920-1940). The values for *frequency of shocks* range from 0.055 to 0.714 with a mean of 0.356 and a standard deviation of 0.102. In other words, the average district in our sample experienced a rainfall shock every three years or had a 35.6% annual probability of having a shock.

The *intensity of shocks* measure is defined as the sum of values exceeding one standard deviation between 1920 and 1940, and it indicates the magnitude of these shocks. The higher the intensity of the shocks, the stronger the hypothesised impact on local farming conditions and long-term patterns of human settlement. The summary statistics of the weather measures are presented in panel (a) of Table 1.

Table 1. *Summary Statistics*

Variable	Obs.	Mean	Std. Dev.	Min	Max
Panel (a): Weather measures					
Ln(Variation of Rainfall)*	221	0.083	0.022	0.034	0.156
Ln(Frequency of Shocks) *	221	0.132	0.033	0.023	0.234
Ln(Intensity of Shocks) *	221	2.127	0.257	1.028	2.580
Average Rainfall *	221	64.316	38.482	15.80	248.74
Panel (b): Population Measures					
Population (1931 census) *	221	411863	557840	1860	2539610
Land Surface (sq. miles) *	221	11871	21895	81	149277
Ln(Population Density) *	221	1.651	0.676	0.063	3.401
Adjusted Population †	221	463646	628414	2023	2876156
Ln(Adjusted Population Density) †	221	3.848	1.638	0.782	7.572
Panel (c): Controls					
Ln(Rainy Season) in months *	221	1.624	0.392	0.693	2.484
Bi-modal Rainfall Dummy *	221	0.318	0.467	0.00	1.00
Coastal Dummy ¢	221	0.389	0.488	0.00	1.00
Navigable River Dummy ¢	221	0.251	0.433	0.000	1.000
Terrain Ruggedness ¥	221	0.808	0.704	0.003	3.563
Elevation °	221	674.321	565.525	9.027	2305.878
Soil organic carbon stock Φ	221	64.203	55.366	28.000	253.000
Cation exchange capacity of soil Φ	221	21.162	10.877	2.000	41.000
Malaria Stability Index Ẍ	221	9.528	8.815	0.000	32.751

Source: * indicates that these variables were assembled by the authors from primary archival sources. See Table A-3 in Appendix for an overview of the sources. *Bi-modal Rainfall:* assigned "1" for every district that has two rainy seasons within a year, and "0" otherwise.

† indicates that these variables were authors' calculations based on Frankema & Jerven (2014) and Maddison's (2010) methods. See Table A-2 in the Appendix for a detailed description.

¢ indicates that these variables were constructed by consulting FAO maps, obtained from http://www.fao.org/nr/water/aquastat/maps/index.stm. *Coastal dummy*: assigned "1" for every district located at the coast and "0"otherwise. *Navigable River dummy:* assigned "1" for every district that a navigable river runs through it and "0"otherwise.

¥ indicates that these variable were authors' calculations by consulting Nunn & Puga (2012), obtained from http://diegopuga.org/data/rugged/. *Terrain Ruggedness*: We compute the mean score of terrain ruggedness for each district in our sample using ArcGIS.

° indicates that these variables were authors' calculations by consulting Jarvis et al., (2008), obtained from http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1. *Elevation:* We compute the mean score of these variable for each district in our sample using ArcGIS. Elevation measures the height (in meters) above mean sea level.

Φ indicates that these variable were constructed by consulting world soil grids database, obtained from http://www.isric.org/content/data. *Soil organic carbon stock and cation exchange capacity of soil*: We compute the mean score of these variable for each district in our sample using ArcGIS. Elevation is measured in meters. Soil organic carbon stock is measured in tons per hectare for depth interval 0.05m – 0.15m. Cation exchange capacity of soil is measured in cmolc/kg at depth 1.00m.

$^{\text{X}}$ indicates that this variable was constructed by consulting Kiszewski et al., (2004), obtained from http://gps.ucsd.edu/faculty-directory/gordon-mccord.html. *Malaria stability index* measures the average prevalence of malaria transmission within each colonial district. The index takes into account the prevalence and type of mosquitoes indigenous to a region, their human biting rate, their daily survival rate, and their incubation period.

5.3.3 Population density estimates

Our population data are obtained from the colonial population censuses conducted in the 1920s and 1930s, and especially the 1931 census that was held throughout the British empire. The difficulties of making accurate population counts are well-known, even for present-day governments, but especially for the poorly equipped colonial administrations of that time. The various biases in African colonial population estimates are widely acknowledged in the literature (Kuczynski, 1948, 1949; Tabutin & Schumacher, 2004; Manning, 2010; Frankema & Jerven, 2014). For the Asian colonies the data are believed to be more accurate, but certainly not flawless. For 19th century Indonesia, for instance, consecutive census estimates suggest almost impossible rates of population growth, even though the estimates for the interwar era are considered to be much more accurate.

The most important problem is that colonial census data tend to underestimate actual population size because of a) a lack of census taking capacity of colonial administrations, who had to rely largely on indigenous chiefs, district officers and village headman to assemble the numbers and b) the political incentives associated with census taking efforts. As information on population size offered a crucial tool to colonial administrations to expand their tax base, respondents and local political leaders often had an incentive to underreport - this wasn't always the case, since promises of subsidies related to population size sometimes had the opposite effect.[19]

That said, the capacity of colonial bureaucracies to conduct censuses did improve over time and as a result the gap between the estimated and actual

[19] The Nigerian census of offers a clear example for this mechanism, but that doesn't distort our estimates here, see Frankema and Jerven (2014).

number of inhabitants was substantially reduced. This is corroborated by studies pointing out that the inter-census growth rates between 1850 and 1950 were often on the high end, and in numerous cases even beyond all probability. In a seminal study by Patrick Manning, a method has been proposed to backward extrapolate population estimates from the 1960s on the basis of a series of decadal default growth rates, to compute the possible error margins of earlier census estimates. For Sub-Saharan Africa Manning's method has been criticized and adjusted by Frankema and Jerven (2014), but their study by and large subscribed to the basic idea of using bandwidth growth rates to adjust disputably low census estimates. But what is more important, their alternative population estimates for the 1930s don't deviate that much from Manning's, since the assumption of different default growth rates doesn't weigh so heavily in the relatively short term interval between 1950 and 1930.

We adopted the backward extrapolation method to check the population estimates in our dataset. We take the 1960 figure as the ultimate benchmark and compute the average annual growth rate between the census estimates of the 1920-1940 era in our original dataset. In line with Frankema and Jerven we assume for African colonies a default annual growth rate of 1.6 in the 1950s, 1.3 in the 1940s, 1.2 in the 1930s and 0.4 in the 1920s. We then compare this level estimate with the actual census estimate and adjust (in virtually all cases upward) the district counts with the obtained percentage. For the Asian colonies we adopt existing adjusted population series from Maddison (2010), which we also checked for population growth rates.

Making overall adjustments on a colony level and thus applying similar rates of correction to all districts within the colony, leaves us with the possible concern that the accuracy of population estimates has also differed across districts. One way to correct for this is to take district level data for 1960 and then apply the backward extrapolation method on a district level. There is a great disadvantage to this method, however, as it erases the possible effects of inter-district migration. We may thus end up correcting one bias by introducing another. We thus decided against it, while knowing that the intra-colony variation in the biases of our district estimates will have to be extremely large to alter the inter-district variation we observe and this gives us considerable confidence that the data we use in the regressions are sufficiently adequate to put our main hypotheses to the test. The summary statistics of population, population density and their adjusted measures are presented in panel (*b*) of Table 1. Appendix Table A-2 presents the original census estimates along with our adjusted estimates and the rates of adjustment in percentages of the original figures. Table A-3 presents the historical sources.

5.3.4 Controls

Our second hypothesis considering the negative relationship between rainfall shocks and population density, will be tested in a multivariate regression framework. This allows us to include a number of additional controls to address omitted variable biases emerging from a range of unobserved factors that are likely to influence historical patterns of human settlement. We control for differences in general climatological conditions such as (a) average rainfall levels, (b) the length of rainy seasons (measured in months), and (c) the existence of bi-modal rainfall patterns. Additionally, we control for differences in physical geography by constructing indicators for (d) elevation, (e) soil ruggedness, (f) cation exchange capacity of soil, (g) soil's organic carbon stock, and by constructing dummies of (h) access to the coast and (i) presence of navigable rivers. Lastly, we control for the (j) prevalence of malaria by calculating for each district the malaria stability index (Kiszewski et al., 2004). The summary statistics for these controls are presented in panel (*c*) of Table 1, along with the sources used to compute them.

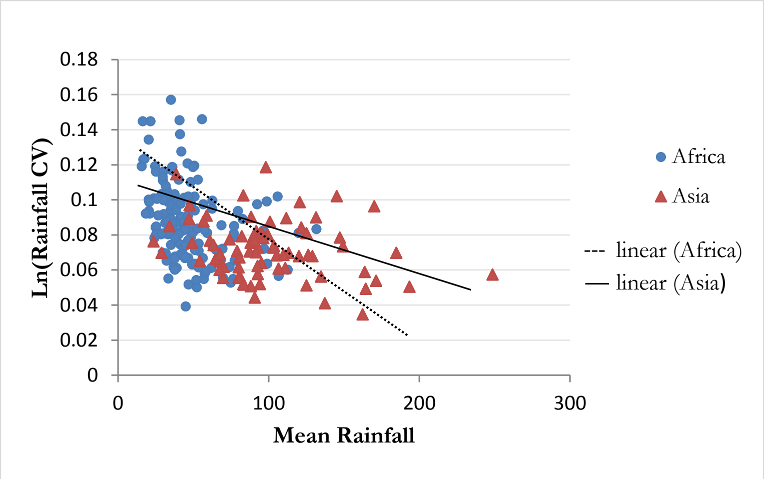
5.4 Did Africans face greater climatological insecurity?

The first part of this section (4.1) focuses on the climatological differences between the tropical areas in the two continents, questioning whether people in tropical Africa, on the whole, faced greater climatological insecurity than in tropical Asia. It presents the results of differences pertaining to the average variation of rainfall, and to the *frequency* and the *intensity* of rainfall shocks. Section 4.2 investigates whether the significant inter-continental difference we find in rainfall variability is produced by any intra-African heterogeneity, and especially a difference in climate systems between East and West Africa, or that it can be regarded as a truly 'African' feature.

5.4.1 Climatological Differences

Figure 4 presents a scatter plot of rainfall variability (Ln rainfall CV) and long-term annual average rainfall levels. We separated our 221 observations into Asian and African districts. The figure shows that the two dot clouds only partially overlap: tropical Africa is dryer than tropical Asian and the variability of rainfall is higher in Africa as well. The scatter plot also shows that the intra-continental variation in rainfall variability is larger in Africa than in Asia.

Figure 4. *Rainfall Variation & Rainfall Mean*



To test the statistical significance of these observations we employ a simple cross-sectional ordinary least square (OLS) regression. The model can be summarized as follows:

$$y = \alpha + \beta_1 \, Continent_i + \beta_2 \, X_i' + \varepsilon_i, \tag{1}$$

where y refers to the tree different measures of climatological variability (panel (*a*), Table 1), *Continent* is a dummy variable that takes the value of 1 if a district *i* is located in Africa and 0 otherwise (i.e. Asia is the reference category). The coefficient of interest is β_1. A positive sign, $\beta_1>0$, indicates that, on average, Africans were confronted with greater climatological instability. X_i' denotes a vector of determinants which we control for, α is a constant, and ε_i is the error term.

Table 2 presents the OLS estimates for the three dependent variables in turn. Columns 1-3 show the *Ln(Variation of Rainfall)* results. The Africa dummy is statistically significant at the 99% confidence interval and suggest that on average African districts, and by extension African countries, experienced higher levels of climatological variability during the 1920s and 1930s (*coeff.= 0.018, SE= 0.002, p-value= 0.000*). The results are robust to controlling for average rainfall mean (column 2), and to clustering standard errors at both the country and district level (column 3).

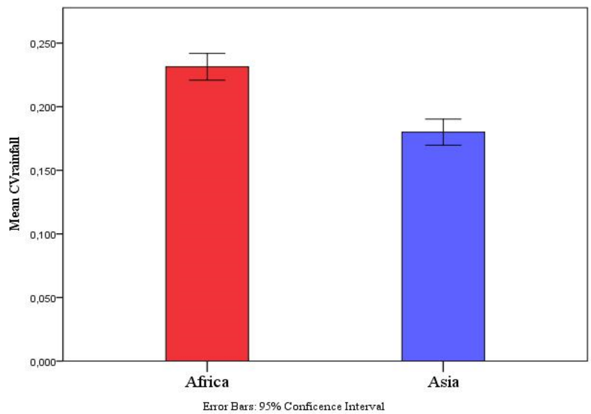
Table 2. *Rainfall Variation in Africa & Asia*

Dependent	Ln(Variation of Rainfall)			Ln(Frequency of Shocks)			Ln(Intensity of Shocks)		
Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Africa	0.0182	0.0111	0.0182	0.0263	0.0251	0.0263	0.1898	0.2553	0.2553
	[6.28]***	[3.01]***	[6.91]***	[6.02]***	[4.45]***	[4.04]***	[5.34]***	[5.65]***	[4.83]***
Rainfall mean		-0.0012			-0.0001			0.0012	
		[-2.89]***			[-0.32]			[2.31]**	
Country effects	N	N	Y	N	N	Y	N	N	Y
F-statistic	47.80	29.96	29.51	36.29	47.80	17.16	28.53	17.23	13.34
R^2	0.152	0.189	0.201	0.143	0.143	0.145	0.117	0.138	0.138
Observations	221	221	221	221	221	221	221	221	221

Notes: Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Reported in parentheses are t-statistics. Standard errors are clustered at the district level, unless stated otherwise. Asia is the reference group [continent=0]. Country effects denote country dummies

The estimated coefficients are presented graphically in Figure 5, together with the error bars set at a 95% confidence interval. It shows that the African districts in our sample experienced significantly more rainfall variation than the Asian districts. Moreover, the mean difference between African and Asian districts is large enough to be meaningful. To illustrate this, we calculated the maximum likelihood estimator (or Cohen's *d*) as a measure of effect size (Cohen, 1988). Cohen's *d* considers the standardized mean difference between two groups using the following formula: $d = (\mu 1 - \mu 2)/s$, where $\mu 1$ and $\mu 2$ are the means for the two groups (in our case Africa and Asia), and s is the pooled standard deviation.

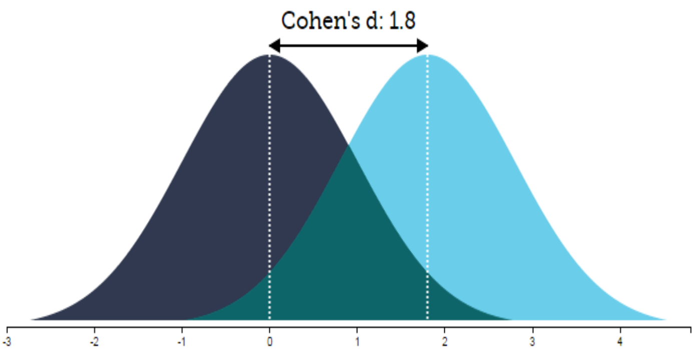
Figure 5. *Variation of Rainfall in Africa & Asia*



Notes: Mean difference between the two continents. This figure presents the estimated coefficients of column 1 in Table 2, including error bars at 95% confidence intervals.

The results point to a substantial difference *d* = 1.789 (Figure 6). In other words, 96.4% of the treatment group (i.e. Africa in our case) will be above the mean of the reference group (Asia), 36.8% of the two groups will overlap, and there is a 89.9% chance that a district picked at random from the treatment group will have a higher score than a district picked at random from the control group. Taking in mind how important rainfall is for systems of rain-fed agriculture in an age where modern farming technologies were just starting to have some impact, the sheer magnitude of the inter-continental difference is a strong indication that the difference in rainfall variability had an impact on the possibilities for agricultural development.

Figure 6: *Visualization of effect size using Cohen's d*

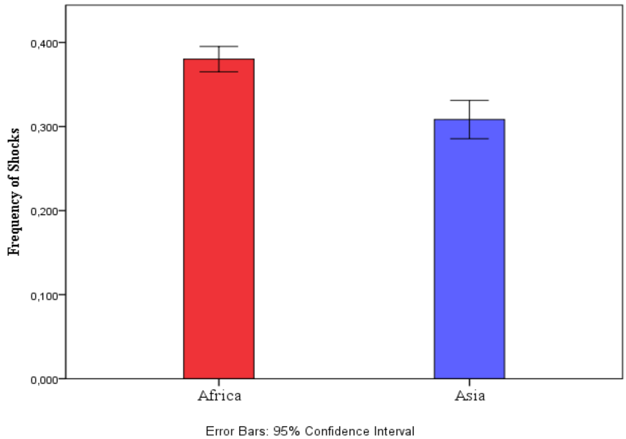


Notes: Author's calculations.

Columns 4-6 in Table 2 show the *Ln(Frequency of shocks)* results. The positive and significant Africa dummy coefficient suggests that, on average, Africans experienced a higher frequency of weather shocks than Southeast Asians (*coeff.= 0.027, SE= 0.004, p-value= 0.000*). The high effect size result (Cohen's *d*= 1.724) again points to a crucial difference. Figure 7-a illustrates the mean difference between the two continents, together with the error bars. Columns 7-9 show the *Ln(Intensity of Shocks)* results. The positive and significant Africa dummy coefficient suggests that, on average, the intensity of the rainfall shocks was larger in tropical Africa, than in tropical Asia (*coeff.= 0.189, SE= 0.038, p-value= 0.000*). The large effect size (Cohen's *d*= 2.845) reveals the climatological adversities African farmers were facing compared to their Asian counterparts. Figure 7-b graphically illustrates the mean difference between the two continents, together with the error bars.

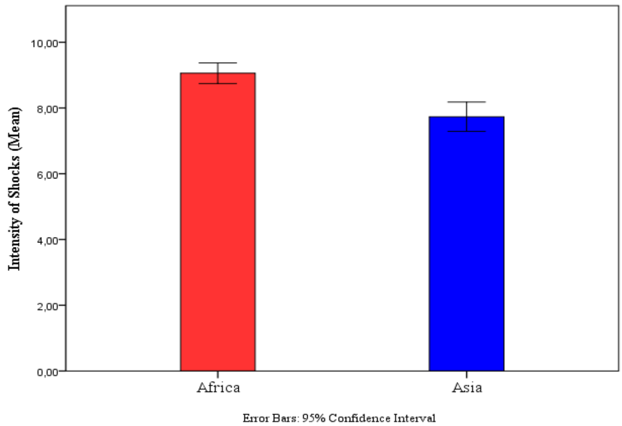
Taken together, our results indicate that rainfall shocks in tropical Africa were both more frequent and more severe than in tropical Asia, translating into higher cultivation risks. In addition, we would like to emphasize that if we would extend this cross-continental comparison with districts or provinces in former French, Belgian or Portuguese African colonies, the results would probably be even more pronounced, for the historical literature generally agrees that the British colonized areas with relatively favourable conditions for tropical agriculture (Burbank & Cooper, 2010, p. 315).

Figure 7-a. *Frequency of Weather shocks, by Continent*



Source: Mean difference of frequency of shocks between the two continents as estimated in column 4 of Table 2. Error bars at 95% confidence interval are included

Figure 7-b. *Intensity of Weather Shocks by Continent*

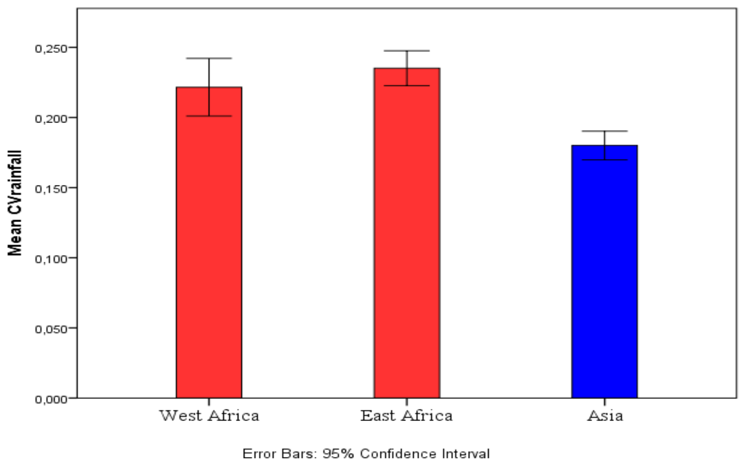


Source: Mean difference of intensity of shocks between the two continents as estimated in column 7 of Table 2. Error bars at 95% confidence interval are included

5.4.2 Intra-African Heterogeneity?

We now proceed by investigating whether the estimated difference between African and Asian districts is driven by any intra-African heterogeneity. To that end, we sub-divided the African sample into two groups (i.e. West and East African districts) and ran a one-way ANOVA that compares *rainfall variation* of these two groups and Asia separately.[20] Figure 8 illustrates the estimated mean differences across the three regions. While both West ($p < .001$) and East ($p < .001$) Africa exhibit significantly more rainfall variation than Asia, the difference between West and East Africa is small and statistically insignificant ($p = .632$). In other words, both regions in the African tropics experienced significantly more rainfall variability than we observe in the Asian tropics.[21]

Figure 8. *Variation of Rainfall across Regions*



Source: Mean difference of rainfall variation across the three regions. Error bars at 95% confidence interval are included

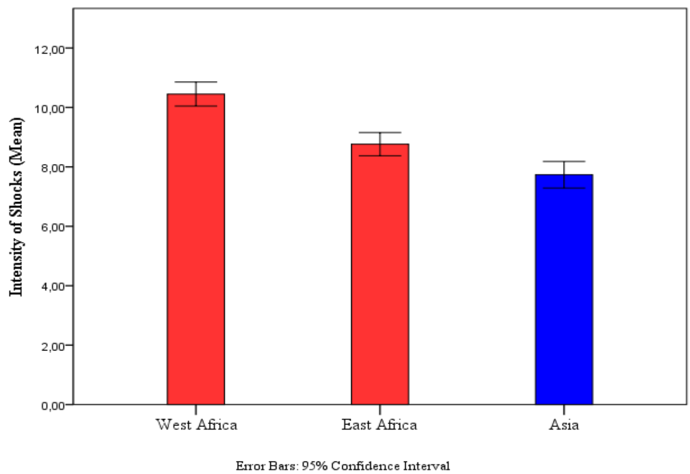
A similar method for the *frequency of shocks* result demonstrates that there exists no intra-African difference ($p = .129$), while in Southeast Asia the

[20] Between-groups comparisons were conducted with Bonferroni corrected t-tests. We preferred this method to simple separate t-tests to avoid inflation of Type I error.

[21] The results remain largely unchanged when we only include districts that are located at the coast. Both West ($p < .001$) and East ($p < .001$) African coastal districts exhibit significantly more rainfall variation than Asian coastal districts. The difference between West and East Africa is statistically significant at 90% confidence interval ($p = .073$).

frequency of rainfall shocks was significantly lower than in either West (p = .013) or East Africa (p < .001). Finally, our results for the *intensity of shocks* indicate that there is a significant intra-African difference (p < .001), as is illustrated in Figure 9. West Africa experienced more severe shocks than East Africa. However, the intensity of shocks in both West (p < .001) and East Africa (p < .001) was significantly more severe than in Asia. These findings thus underpin our argument that the Asia-Africa distinction in climatological variability is real.

Figure 9. *Intensity of Shocks across Regions*



Source: Mean difference of intensity of shocks across the three regions. Error bars at 95% confidence interval are included

5.5 Rainfall Variability & Population Density

We now proceed to test our second hypothesis regarding the negative relationship between rainfall variability and population densities in a multivariate regression framework. Section 5.5.1 presents our baseline results and section 5.5.2 deals with several concerns that may violate our empirical strategy in order to indicate how robust our findings are.

5.5.1 Baseline Results

Figure 10 shows scatter plots with mean rainfall on the y-axis and the lognormal of population densities on the x-axis. The dots represent African districts, the triangles the Asian districts. Figure 10 shows that the clouds are only partly overlapping, with Asian areas generally characterized by higher average rainfall levels and higher population densities. The figure also shows a positive correlation between both variables, although the variation around the linear trend line is large.

Figure 10. Rainfall Mean & Population Density

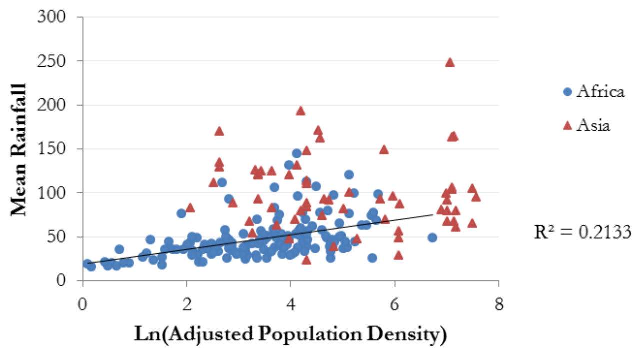


Figure 11 shows the relationship between rainfall variability and population densities, again showing only a partial overlap between the clouds. Figure 11 also shows a negative relationship between rainfall variability and population densities.

Figure 11. Rainfall Variation & Population Density

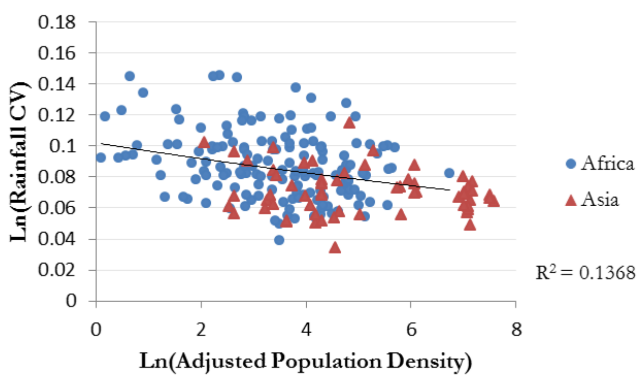


Table 3 presents our baseline OLS regression results, with rainfall shocks as the main independent variable of interest, and rainfall means as our most important control variable. The dependent variable is the adjusted population density. Column 1 shows the OLS result without any controls (*coeff.= -26.061, SE= 4.913, p-value= 0.000*). The R^2 suggests that rainfall variability explains approximately 14.4% of the variation in population density. To avoid potential multicollinearity problems, we include our controls one by one. Columns 2-7 present the results after controlling for continental differences (column 2), mean rainfall levels (column 3), length of rainy season (column 4), uni-modality of rainfall (column 5), access to the sea (column 6), navigable rivers (column 7), terrain ruggedness (column 8), elevation (column 9), cation exchange capacity (column 10) and malaria stability index (11). Across all specifications, the results of *Ln(RainfallCV)* remain robust and statistically significant at a 99 per cent confidence interval. Moreover, all controls yield the expected sign, which serves as an additional validation of our analysis. Finally, in column 12, we jointly include all the controls and add country fixed effect dummies. This last specification is the one we use for our conclusions, as it controls for a range of omitted variables and yields the highest R^2 of 0.476 (or 47.6 per cent).

Table 3. *Rainfall Variation* & *Adjusted Population density in Africa* & *Asia*

	Dep. Variable: Log Population Density Adjusted											
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ln(RainfallCV)	-26.061	-16.461	-15.665	-26.093	-23.507	-21.188	-25.912	-24.271	-25.129	-22.047	-23.106	-19.580
	[-5.30]***	[-3.52]***	[-3.52]***	[-5.15]***	[-4.76]***	[-4.83]***	[-5.29]***	[-5.38]***	[-5.27]***	[-5.14]***	[-5.21]***	[-5.88]***
Africa		-0.6357										-0.2612
		[-5.32]***										[-2.01]**
Rainfall mean			0.0152									0.0091
			[5.45]***									[3.26]***
Wet season				-0.0351								-0.1293
				[-0.66]								[-1.71]*
Bi-modal rainfall					0.5432							0.4192
					[2.58]**							[2.27]**
Access to the sea						1.3264						0.2962
						[6.52]***						[1.95]*
Navigable river							-0.0821					0.0096
							[-0.37]					[-0.04]
Terrain ruggedness								0.5475				0.7413
								[3.89]***				[4.88]***
Elevation									-0.0007			-0.0006
									[-4.69]***			[-2.74]***
Cation exchange capacity										0.0667		0.0660
										[7.50]***		[5.17]***
Malaria stability index											-0.0241	-0.0181
											[-2.83]***	[-2.44]**
Country effects	N	N	N	N	N	N	N	N	N	N	N	Y
F-statistic	28.13	29.11	28.09	12.34	16.38	32.17	10.60	20.76	21.98	40.62	17.38	16.52
R^2	0.144	0.221	0.234	0.145	0.239	0.262	0.145	0.175	0.194	0.323	0.199	0.476
No. observations	221	221	221	221	221	221	221	221	221	221	221	221

Notes: Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Reported in parentheses are t-statistics. Standard errors are clustered at the district level. Asia is the reference group [continent=0]. Country effects denote country dummies. Wet season is measured in months. Bi-modal rainfall refers to the presence of two wet periods within a year. For a full description of the control variables see Table 1.

5.5.2 Robustness Checks

We now check the robustness of our results as reported in Tables 2 and 3. One potential concern is that the estimates are driven by outliers both in our dependent and independent variables. To deal with such concerns, we follow a conservative and strict method of excluding outliers as developed by Leys et al. (2013). In practise, we exclude any observation that exhibits a higher than 3 and lower than -3 standard deviations from the mean. The results remained largely unchanged (not reported).

Another possible concern is that the problems of undercounting in the population census of 1931 were more serious in the colonial hinterlands than in or around the capital districts, where the bureaucratic capacity required to conduct censuses was obviously higher. To check the possible impact of uneven biases in the population census, we classified the districts in our sample in three groups: 1) the capital district, 2) districts bordering the capital district and, 3) a rest category of so-called ‘hinterland districts’. To correct for the possibility that undercounting was more severe in the hinterland districts, we differentiated the mark-up rates which we hitherto had applied on the colony level; we maintained the national mark-up rate for districts bordering the capital, added another 50% to hinterland districts and allocated to the capital districts whatever there was left. The results remained largely unchanged and are presented in Table A-4 in the Appendix.

Lastly, to be sure that our sample is not driven by sample selection, we included historical rainfall observations for India. We obtained data from the Indian Institute of Tropical Meteorology (IITM).[22] These data have been previously used by Michalopoulos (2012) and Fenske and Kala (2015). The

[22] See http://www.tropmet.res.in/static_page.php?page_id=53.

results yield nearly identical results (not reported).[23] Unfortunately, we were not able to test our second hypothesis related to population density, since, throughout the colonial period, several reorganization of district and other administrative boundaries occurred in India, restricting us from getting consistent estimates for population density.

5.6 Conclusion

Studies in the New Economic Geography have made it overly clear that the spatial distribution of economic agglomerations and associated concentrations of human settlements have deep ecological roots. Abundant and predictable rainfall is one of the key variables for explaining such settlement patterns, since rain-fed agriculture served as the basis of subsistence in pre-modern societies, and still is a highly important factor in explaining divergent trajectories of agricultural development.

This study has used a new dataset of annual and monthly district-level rainfall patterns to assess the longstanding idea that climatological conditions were more conducive to the development of dense rural populations in Asia than in Africa. Although we were not able to prove the direct causal connection of rainfall to population density, via its effect on agricultural intensification, we claim to have taken this research a step further by exploring the relationship between rainfall patterns and human settlement using a more fine-grained dataset of rainfall and population levels, and testing the impact of various measures of rainfall variability, for an era preceding large scale global carbon emissions and the demographic explosion of the second half of the 20th century. We thus managed to avoid part of the noise inherent to studies using contemporary rainfall and population data and also go beyond the level of cross-country comparisons.

[23] Figure A-1 in the Appendix illustrates the estimated mean differences across the four regions (West Africa, East Africa, South-east Asia and India), together with the estimated error bars at 95% confidence interval. Both South-east Asia and India experienced significantly less rainfall variability than we observe in the African tropics.

Our study confirms the existence of significant cross-regional differences in both the frequency and intensity of rainfall shocks and have shown that these were not driven by any intra-African heterogeneity, even though climate systems in the tropical regions of West and East Africa are different. We also found evidence for the hypothesis that there are countervailing effects of rainfall *levels* and rainfall *variability* on the evolution of human settlements. When controlling for mean levels of rainfall, districts with greater insecurity of rains held lower population densities, and these effects were strong and robust, accounting for circa 14% of the variation. This study thus adds support to the view that the climatological challenges posed to agricultural development were larger in tropical Africa than in tropical Asia, and that this may be one of the keys to understand why large parts of tropical Asia have historically been more densely populated than tropical Africa. And in so far higher degrees of climatological variability posed more severe constraints to the adoption of modern productivity-enhancing farming technologies, this may also partially account for the diverging trajectories of agricultural development in the post-1960 era.

References

Alsan, M. (2014). The effect of the tsetse fly on African development. *The American Economic Review*, *105*(1), 382-410.

Austin, G. (2008). Resources, techniques, and strategies south of the Sahara: revising the factor endowments perspective on African economic development, 1500–20001. *The Economic History Review*, *61*(3), 587-624.

Bloom, D. E., Sachs, J. D., Collier, P., & Udry, C. (1998). Geography, demography, and economic growth in Africa. *Brookings papers on economic activity*, *1998*(2), 207-295.

Booth, D., Dietz, A. J., Golooba-Mutebi, F., Fuady, A. H., Henley, D., Kelsall, T., & van Donge, J. K. (2015). Developmental Regimes in Africa synthesis report.

Braudel, F. (1995). *The Mediterranean and the Mediterranean world in the age of Philip II* (Vol. 2). University of California Press.

Burbank, J., & Cooper, F. (2010). *Empires in world history : power and the politics of difference*. Princeton, N.J.: Princeton University Press.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Collier, P. (2008). *The Bottom Billion. Why the Poorest Countries Are Failing and What Can Be Done About it*. Oxford: Oxford University Press.

Conway, G. (1998). *The doubly green revolution : food for all in the twenty-first century*. Ithaca, N.Y.: Comstock Pub. Associates.

Diamond, J. (1997). *Guns, Germs and Steel. The Fates of Human Societies*. New York: W.W. Norton & Company.

Djurfeldt, G., Holmén, H., Jirström, M., & Larson, R. (2005). *The African food crisis: lessons from the Asian Green Revolution*. Wallingford, UK.

Frankema, E., & Jerven, M. (2014). Writing history backwards or sideways: towards a consensus on African population, 1850-2010. *Economic History Review*, 67(4), 907-931.

Frankema, E. (2014). Africa and the Green Revolution. A Global Historical Perspective. *NJAS - Wageningen Journal of Life Sciences*, 70-71, 17-24

Frankema, E. (2015). The biogeographic roots of world inequality: Animals, disease, and human settlement patterns in Africa and the Americas before 1492. *World Development*, *70*, 274-285.

Gallup, J. L., Sachs, J. D., & Mellinger, A. D. (1999). Geography and Economic Development. *International Regional Science Review*, 22(2), 179-232.

Giannini, A., Biasutti, M., & Verstraete, M. M. (2008). A climate model-based review of drought in the Sahel: Desertification, the re-greening and climate change. *Global and Planetary Change*, 64(3-4), 119-128.

Goody, J. (1980). *Technology, tradition and the state in Africa*. CUP Archive.

Hayami, Y. (2000). An Ecological and Historical Perspective on Agricultural Development in Southeast Asia. *Policy Research Working Papers, 2296*. Development Research Group, World Bank Washington, DC.

Hayami, Y., Platteau, J.-P., & Dasgupta, P. (1998). Resource Endowments and Agricultural Development: Africa versus Asia. In Y. Hayami & M. Aoki (Eds.), *The institutional foundations of East Asian economic development: proceedings of the IEA conference held in Tokyo, Japan* (pp. 357-412). New York, N.Y.: St. Martin's Press in association with the International Economic Association.

Krugman, P. (1993). First nature, second nature and metropolitan location. *Journal of Regional Science*, 33, 129-144.

Kuczynski, R. R. (1948). *Demographic Survey of the British Colonial Empire. Volume I: West Africa*. London: Royal Institute of International Affairs, Oxford University Press.

Kuczynski, R. R. (1949). *Demographic Survey of the British Colonial Empire. Volume II: East Africa*. London: Royal Institute of International Affairs, Oxford University Press

Le Blanc, D., & Perez, R. (2008). The relationship between rainfall and human density and its implications for future water stress in Sub-Saharan Africa. *Ecological Economics*, *66*(2), 319-336.

Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology*, *49*(4), 764-766.

Maddison, A. (2010). Statistics on world population, GDP and per capita GDP, 1-2008 AD. *Historical Statistics*. Data retrieved at 22-05-2016 from The Maddison-Project (2013 version): http://www.ggdc.net/maddison/maddison-project/home.htm.

Mainguet, M. (1999). *Aridity: droughts and human development*. Berlin; New York: Springer.

Manning, P. (2010). African Population: Projections, 1851-1961. In K. Ittmann, D. D. Cordell, & G. H. Maddox (Eds.), *The Demographics of Empire. The Colonial Order and the Creation of Knowledge* (pp. 245-275). Athens, Ohio: Ohio University Press.

Olsson, O., & Hibbs, D. A. (2005). Biogeography and Long-run Economic Development. *European Economic Review*, 49(4), 909-938.

Otsuka, K., & Larson, D. F. (Eds.). (2013). *An African green revolution: finding ways to boost productivity on small farms*. Dordrecht; New York: Springer.

Papaioannou, K. J. (2016). Climate shocks and conflict: Evidence from colonial Nigeria. *Political Geography*, *50*, 33-47.

Papaioannou, K. J. (2017). 'Hunger Makes a Thief of Any Man': Poverty and Crime in British Colonial Asia. *European Review of Economic History*, 21(1), 1-28

Papaioannou, K. J., & De Haas, M. (2017). Climate Shocks Cash Crops and Resilience: Evidence from Colonial Tropical Africa. *World Development*, 94(1), 346–365.

Sachs, J. D., & Warner, A. M. (1997). Sources of slow growth in African economies. *Journal of African Economies*, 6(3), 335-376.

Smaling, E. M. A., & Braun, A. R. (1996). Soil fertility research in sub-Saharan Africa: New dimensions, new challenges. *Communications in Soil Science and Plant Analysis*, 27(3-4), 365-386.

Strahler, A. H., & Strahler, A. N. (1992). *Modern physical geography*. New York: Wiley.

Tabutin, D., & Schoumaker, B. (2004). The Demography of Sub-Saharan Africa from the 1950s to the 2000s. A Survey of Changes and a Statistical Assessment. *Population (English Edn.)*, 59(3/4), 457-555.

Tosh, J. (1980). The Cash-crop Revolution in Tropical Africa: An Agricultural Reappraisal. *African Affairs*, 79(314), 79-94.

Vavilov, N. I. (1951). *The origin, variation, immunity and breeding of cultivated plants: selected writings of N.I. Vavilov*. Waltham, Mass.: Chronica Botanica.

Verschuren, D., Laird, K. R., & Cumming, B. F. (2000). Rainfall and drought in equatorial east Africa during the past 1,100 years. *Nature*, *403*(6768), 410-414.

Appendix

Table A-1. *Colonial Districts, c.1940*

Country	District	Country	District
Ceylon	Western Province	Tanganyika	Arusha
Ceylon	Central Province	Tanganyika	Bagamoyo
Ceylon	Southern Province	Tanganyika	Biharamulo
Ceylon	Northern Province	Tanganyika	Bukoba
Ceylon	Eastern Province	Tanganyika	Dar es Salaam
Ceylon	North-Western Province	Tanganyika	Dodoma
Ceylon	North-Central Province	Tanganyika	Handeni
Ceylon	Uva Province	Tanganyika	Iringa
Ceylon	Sabaragamuva Province	Tanganyika	Kahama
Brunei	Brunei	Tanganyika	Kigoma
Unfederated Malay States	Kedah	Tanganyika	Kilosa
Unfederated Malay States	Perlis	Tanganyika	Kilwa-Liwale
Unfederated Malay States	Trengganu	Tanganyika	Kondoa-Irangi
Unfederated Malay States	Johore	Tanganyika	Kwimba
Unfederated Malay States	Kelantan	Tanganyika	Lindi
Strait Settlements	Singapore	Tanganyika	Mahenge
Strait Settlements	Penang	Tanganyika	Masasi
Strait Settlements	Malacca	Tanganyika	Maswa
Federated Malay States	Perak	Tanganyika	Mbeya
Federated Malay States	Selangor	Tanganyika	Mbulu
Federated Malay States	Negri Sembilan	Tanganyika	Mikindani
Federated Malay States	Pahang	Tanganyika	Morogoro
North Borneo	Sandakan	Tanganyika	Moshi
North Borneo	East Coast Residency	Tanganyika	Musoma
North Borneo	Kudat	Tanganyika	Mwanza
North Borneo	West Coast Residency	Tanganyika	Newala
North Borneo	Interior Resididency	Tanganyika	Njombe
Indonesia	Serang	Tanganyika	Nzega
Indonesia	Batavia	Tanganyika	Pangani
Indonesia	Buitenzorg	Tanganyika	Pare
Indonesia	Indramajoe	Tanganyika	Utete
Indonesia	Tombo	Tanganyika	Rungwe
Indonesia	Bandoeng	Tanganyika	Shinyanga
Indonesia	Malabar	Tanganyika	Singida
Indonesia	Semarang	Tanganyika	Songea
Indonesia	Kranggan	Tanganyika	Tabora
Indonesia	Poerwokerto	Tanganyika	Tanga
Indonesia	Wonosobo	Tanganyika	Tunduru
Indonesia	Poerworedjo	Tanganyika	Ufipa-Sumbawanga
Indonesia	Magelang	Tanganyika	Usambara
Indonesia	Jogjakarta	Zanzibar	Zanzibar

Indonesia	Soerakarta	Zanzibar	Pemba
Indonesia	Soerabaja	Kenya	Digo
Indonesia	Kediri	Kenya	Malindi - Kilifi
Indonesia	Malang	Kenya	Mombasa
Indonesia	Tosari	Kenya	Lamu
Indonesia	Djember	Kenya	Kitui
Indonesia	Asembagoes	Kenya	Teita
Indonesia	Palembang	Kenya	Narok
Indonesia	Lahat	Kenya	Kajiado
Indonesia	Medanpoetri	Kenya	Machakos
Indonesia	Benkoelen	Kenya	Meru
Indonesia	Padang	Kenya	Embu
Indonesia	Sibolga	Kenya	South Nyeri
Indonesia	Padangsidimpoean	Kenya	Fort Hall
Indonesia	Koetaradja	Kenya	Nairobi
Indonesia	Pontianak	Kenya	Kiambu
Indonesia	Poetoessibau	Kenya	Naivasha
Indonesia	Bandjermasin	Kenya	Laikipia
Indonesia	Balikpapan	Kenya	Nakuru
Indonesia	Longiram	Kenya	Kericho
Indonesia	Manado	Kenya	South Kavirondo
Indonesia	Tondano	Kenya	North Kavirondo
Indonesia	Paloe	Kenya	Trans-Nzoia
Indonesia	Rantepao	Kenya	Uasin-Gishu
Indonesia	Makassar	Kenya	Nandi
Indonesia	Sindjai	Kenya	Northern Frontier
Indonesia	Ternate	Kenya	Kisumu-Londiani
Indonesia	Amboina	Kenya	Elgeyo
Indonesia	Banda	Nyasaland	Lower Shire
Indonesia	Manokwari	Nyasaland	Chikwawa
Indonesia	Merauke	Nyasaland	Cholo
Indonesia	Koepang	Nyasaland	Mlanje
Indonesia	Waingapoe	Nyasaland	Blantyre
Indonesia	Ampenan	Nyasaland	Chiradzulu
Indonesia	Singaradja	Nyasaland	Zomba
Bechuanaland	Francistown	Nyasaland	Upper Shire
Bechuanaland	Tuli Block	Nyasaland	South Nyasa
Bechuanaland	Gaberones	Nyasaland	Ncheu
Bechuanaland	Ngamiland	Nyasaland	Dedza
Bechuanaland	Serowe	Nyasaland	Ft. Manning
Bechuanaland	Lobatsi	Nyasaland	Lilongwe
Bechuanaland	Kanye	Nyasaland	Dowa
Bechuanaland	Molepolole	Nyasaland	Kota Kota
Bechuanaland	Kasane	Nyasaland	Kasungu
Bechuanaland	Ghanzi	Nyasaland	Mombera
Nigeria	Colony	Nyasaland	West Nyasa

Nigeria	Oyo	Nyasaland	North Nyasa
Nigeria	Ondo	Northern Rhodesia	Livingstone
Nigeria	Abeokuta	Northern Rhodesia	Kasama
Nigeria	Calabar	Northern Rhodesia	Mongu
Nigeria	Owerri	Northern Rhodesia	Mpika
Nigeria	Warri	Northern Rhodesia	Abecorn
Nigeria	Benin City	Northern Rhodesia	Ndola
Nigeria	Onitsha	Northern Rhodesia	Mazabuka
Nigeria	Ogoja	Northern Rhodesia	Lusaka
Nigeria	Sokoto	Uganda	Mengo
Nigeria	Kano	Uganda	Entebbe
Nigeria	Kaduna	Uganda	Masaka
Nigeria	Bornu	Uganda	Mubende
Nigeria	Yola	Uganda	Kitgum
Nigeria	Bauchi	Uganda	Bugondo
Nigeria	Zaria	Uganda	Teso
Nigeria	Ilorin	Uganda	Lango
Nigeria	Kontagora	Uganda	Toro
Nigeria	Benue	Uganda	Ankole
Gambia	Bathurst	Uganda	Kigezi
Sierra Leone	Freetown	Uganda	Gulu
Sierra Leone	Bonthe Sherbro	Uganda	Butiaba
Sierra Leone	Pujehun	Uganda	West Nile
Sierra Leone	Moyamba		
Sierra Leone	Kennema		
Sierra Leone	Batkanu		
Sierra Leone	Kaballa		
Ghana	Accra		
Ghana	Addah		
Ghana	Quittah (Keta)		
Ghana	Cape Coast		
Ghana	Seccondee		
Ghana	Tarquah (Tarkwa)		
Ghana	Axim		
Ghana	Coomassie (Kumasi)		
Ghana	Sunyani		
Ghana	Kintampo		
Ghana	VoltaRiver		
Ghana	Eastern Dagoma		

Source: See main text.

Table A-2. *Population Data & Sources*

Country	Census 1931	Adjusted Population	Level Diff.	% Diff.
Africa		**Frankema & Jerven (2014)**		
Tanganyika	4,972,807	5,647,316	674,509	11.94%
Zanzibar	235,307	235,307	255,451	8.56%
Kenya	2,966,993	4,486,109	1,519,116	33.86%
Nyasaland (Malawi)	1,603,451	2,126,786	523,335	24.61%
Northern Rhodesia (Zambia)	1,393,258	1,781,304	388,046	21.78%
Bechuanaland (Botswana)	260,064	285,172	25,108	8.80%
Nigeria	19,928,171	24,860,435	4,932,264	19.84%
Gambia	185,150	217,034	31,884	14.69%
Sierra Leone	1,667,790	1,435,083	-232,707	-16.22%
Gold Coast (Ghana)	3,160,386	3,870,441	710,055	18.35%
Uganda	3,553,534	3,807,693	254,159	6.67%
Asia		**Maddison (2010)**		
Federated Malay States	1,770,486			
Unfederated Malay States	1,487,992			
North Borneo	277,367			
Straits Settlements	1,114,015 (+)			
Malaysia	4,649,860	4,513,000	-136,860	-3.03%
Singapore	603,163	563,000	-40,163	-7.13%
Ceylon (Sri Lanka)	5,312,548	5,312,548	5,748,000	7.58%
Brunei	30,135	31,345	1,210	4.01%
Dutch East Indies (Indonesia)	55,980,765	62,877,930	6,897,165	10,97%

Notes: See Table A-3 for sources used.

Table A-3. *Historical Sources*

The data for the British colonies in Africa and Asia were obtained from the archives of the Colonial Office in the British National Archive (TNA, London). We used information published in *Statistical yearbooks* and *Government reports*:

Africa

The Colony & Protectorate of Nigeria, *Blue Book*. Lagos: Government Printing Office, various issues.

______ *Annual Report*. Lagos: Government Printing Office, various issues,

Nyasaland Protectorate, *Blue Book*. Zomba: Government Printing Office, various issues.

______ *Annual Report*. Zomba: The Government Printer, various issues.

Sierra Leone, *Blue Book*. Freetown: Government Printing Office, various issues.

______ *Annual Report*. Freetown: The Government Printer, various issues.

The Colony & Protectorate of Kenya, *Blue Book*. Nairobi: Government Printing Office, various issues.

______ *Annual Report*. Nairobi: The Government Printer, various issues.

The Colony of the Gambia, *Blue Book*. Bathurst: Government Printing Office, various issues.

______ *Annual Report*. Bathurst: The Government Printer, various issues.

The Gold Coast Colony, *Blue Book*. Accra: Government Printing Office, various issues.

______ *Annual Report*. Accra: The Government Printer, various issues.

The Tanganyika Territory, *Blue Book*. Dar es Salaam: Government Printing Office, various issues.

______ *Annual Report*. Dar es Salaam: The Government Printer, various issues.

The Uganda Protectorate, *Blue Book*. Kampala: Government Printing Office: various issues.

______ *Annual Report*. Entebbe: The Government Printer, various issues.

Northern Rhodesia, *Blue Book*. Livingstone: Government Printing Office, various issues.

______ *Annual Report*. Livingstone: The Government Printer, various issues.

Bechuanaland Protectorate, *Blue Book*. Mafeking: Government Printing Office, various issues.

______ *Annual Report*. Mafeking: The Government Printer, various issues.

Asia

The State of Brunei, *Annual Report*. Singapore: Government Printing Office, various issues.

The State of Ceylon, *Blue Book*. Colombo: The Government Printer, various issues.

______ *Administration Report*. Colombo: The Government Printer, various issues.

The State of Kedah & Perlis, *Administration Report*. Penang: The Government Printer, various issues.

The State of Johore, *Annual Report*. Kuala Lumpur: F.M.S. Government Printing Office, various issues.

Kelantan, *Administration Report*. Kuala Lumpur: F.M.S. Government Printing Office, various issues.

The Federated Malay States, *Blue Book*. Kuala Lumpur: F.M.S. Government Printing Office, various issues.

______ *Annual Report*. Kuala Lumpur: F.M.S. Government Printing Office, various issues.

Crown colony of British North Borneo, *Blue Book*. Jesselton: Government Printing Office, various issues.

______ *Administration Report*. Jesselton: Government Printing Office, various issues.

Straits Settlements, *Blue Book*. Singapore: Government Printing Office, various issues.

______ *Annual Report*. Singapore: Government Printing Office, various issues.

The State of Trengganu, *Administration Report*. Singapore: The Government Printing Office, various issues.

Dutch East-Indies (Indonesia)

Jaarcijfers voor het Koninkrijk der Nederlanden. Kolonien = Statistics Yearbook of the Netherlands. Colonies, various issues: 1899-1923. *Publisher*: 's-Gravenhage, Belinfante.

Statistch jaaroverzicht van Nederlandsch-Indie = Statistical Abstract for the Netherlands East-Indies, various issues: 1924-1930. *Publisher:* Buitenzorg: Statistisch Kantoor van het Department van Landbouw, Nijverheid en Handel.

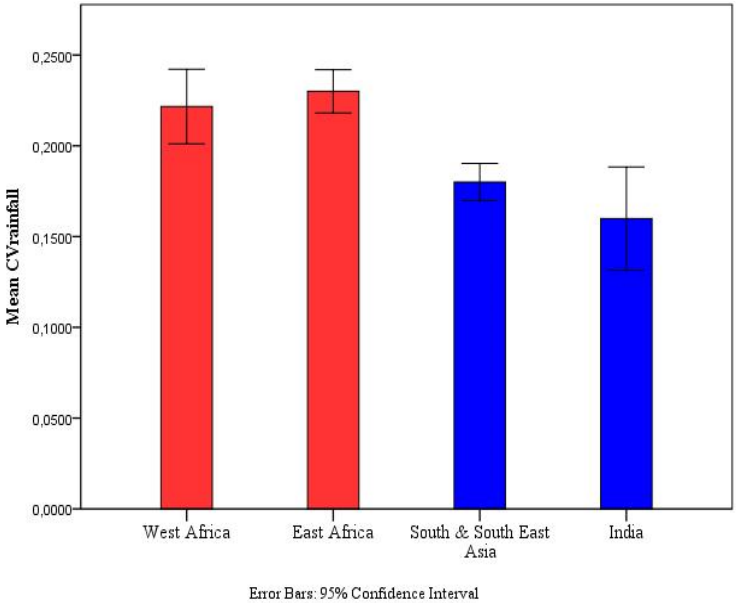
Indisch verslag. II, Statistisch jaaroverzicht van Nederlandsch-Indie = Indian report. II, Statistical abstract for the Netherlands East-Indies, various issues: 1931-1941. *Publisher:* Batavia, Centraal Kantoor voor de Statistiek van het Departement van Landbouw, Nijverheid en Handel.

Table A-4. *Rainfall Variation & Population Density Unevenly Adjusted*

	Dep. Variable: Log Population Density Adjusted											
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ln(RainfallCV)	-27.774	-18.202	-16.985	-27.839	-25.541	-22.845	-27.597	-26.058	-27.597	-27.321	-24.156	-17.011
	[-5.15]***	[-3.46]***	[-3.44]***	[-5.03]***	[-4.74]***	[-4.69]***	[-5.18]***	[-5.12]***	[-5.18]***	[-5.14]***	[-5.21]***	[-3.64]***
Africa		-1.2588										-0.2071
		[-5.27]***										[-1.62]
Rainfall mean			0.0158									0.0107
			[5.54]***									[3.52]***
Wet season				-0.0373								-0.1060
				[-0.69]								[-2.12]**
Bi-modal rainfall					0.4436							0.3011
					[2.00]**							[1.43]
Access to the sea						1.3422						0.9051
						[6.53]***						[1.88]*
Navigable river							-0.0990					-0.0261
							[-0.42]					[-0.11]
Terrain Ruggedness								0.5319				0.6789
								[3.48]***				[3.81]***
Elevation									-0.0007			-0.0001
									[-4.66]***			[-2.38]***
Cation exchange capacity										0.0661		0.0651
										[7.31]***		[5.65]***
Malaria stability index											-0.020	-0.017
											[-2.09]**	[-1.97]**
Country effects	N	N	N	N	N	N	N	N	N	N	N	Y
F-statistic	26.53	28.33	22.00	12.68	14.33	30.80	13.43	18.36	20.90	37.14	18.44	13.48
R^2	0.135	0.221	0.239	0.135	0.143	0.276	0.136	0.175	0.197	0.316	0.153	0.451
No. observations	221	221	221	221	221	221	221	221	221	221	221	221

.Notes: ***Notes:*** Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Reported in parentheses are t-statistics. Standard errors are clustered at the district level. Asia is the reference group [continent=0]. For a full description of the control variables see Table 1

Figure A-1. *Variation of Rainfall across Regions*



Source: Mean difference of rainfall variation across the four world regions. Error bars at 95% confidence interval are included

CHAPTER 6

Conclusion

"*Historia est Magistra Vitae*" [History is a teacher of life]

–Cicero, *De Oratore*, 55 BCE

6.1 General Discussion

For centuries, many thinkers and scholars have sought to understand how climate affects society and the economy. The answer promises insights into why some economies have thrived *historically* while others languished, how *contemporary* societies can design effective policies and institutions against current climate extremes, and into how *future* climate change may impact human habitation. In recent years, a proliferation of rigorous studies has emerged across the social sciences with the aim to quantify and assess the causal effects of climate on economically and societally relevant outcomes. This surge can be partly explained by rising public concerns about climate change and its potentially ensuing distortive effects on societal cohesion; partly by greater popular awareness of the critical role that climate might play in driving economic outcomes; and partly by methodological advances and data availability, combined with improvements in computing power. This dissertation was inspired by, and is part of, this new wave of research.

The main innovative aspect of this thesis lies in its interdisciplinary methodological approach and in its promise to provide new insights from a historical social context that has not yet been subjected to this kind of analysis (i.e. British colonial Africa and Asia). By merging the theoretical and empirical insights of several strands of literature –including economic history, geography and the new climate-economy literature, it aims to simultaneously address both an *academic challenge* (i.e. identification of the causal effects of climate on society) and a *social question* of prime importance (i.e. revealing key mitigating factors that would enable relatively poor rural communities to target their policy interventions).

To achieve its research objectives, the present thesis followed a five-stage approach. The first stage was to systematically *compile* an extensive dataset on a wide variety of indicators, which were completely obtained from primary archival material. The second stage was to econometrically *assess* the impact of climate extremes on a range of selected indicators –including crop yields, crime rates and conflict. The third stage was to *identify* the underlying mechanism that drives the climate-society relationship –namely loss of agricultural income. The fourth stage was to *investigate* heterogeneous (either mitigating or aggravating) effects, as illustrated in Chapters 2 & 3. The fifth stage was to *expose* the medium and long-run consequences of climatic variability as shown in chapter 5, in which we find that the adverse climatological conditions posed higher challenges to agricultural productivity growth in tropical Africa than in tropical Asia, partially accounting for the diverging trajectories of agricultural development in the post-1960 era.

Throughout this dissertation, we make functional use of novel archival sources (a) to formulate theoretical hypotheses by taking the local context into consideration, (b) to obtain a more thorough understanding of the important mechanisms driving the relationship of interest, and (c) to add a new layer of robustness by backing up the regression results. Although extensive research has been carried out on the climate-society nexus, no single study exists that combines econometric analysis with extensive qualitative evidence. We believe that such a two-pronged methodological approach will serve as a base for future studies in this field.

The next sections review the main lessons learned from each chapter, discussing the resulting policy recommendations, and the implications for future research. Overall, our ambition is that this study's insights should prove particularly valuable to both academics as well as to policy makers interested in the impact of climate extremes on food crises, conflicts and societies over the long run.

6.2 Climate & Conflict in Africa

While optimism abounds about Sub-Saharan Africa's recent economic performance and future prospects, other communities across the continent continue to be exposed to episodes of violent conflict, most recently in coastal Kenya, northern Nigeria, South Sudan, the Central African Republic and Mali. While each of these episodes of conflict was motivated ethnically, ideologically or politically, a wide range of studies has indicated that exogenous shocks, such as climate extremes, play an important role in triggering and sustaining conflict (Hsiang et al., 2013; Burke et al., 2014). It is no surprise that violent conflicts often erupt in low-income rural areas which are highly dependent on rain-fed agriculture, have limited access to markets and trade, and are noted for the absence or fragile presence of the state (Blattman & Miguel, 2010; Papaioannou & van Zanden, 2015).

In Chapter 2, we put this theoretical hypothesis under scrutiny by looking at the impact of climate shocks on the incidence of conflict in colonial Nigeria (1912-1945). This investigation takes the form of a historical micro-level case-study. We argue that colonial Nigeria offers an interesting case for several reasons. As West Africa's largest and most populous nation, it contains a wide range of geographical and institutional features within its borders and consequently, meaningful comparisons could be derived. Primary historical sources on court cases, prisoners and homicides were used to capture conflict. To measure climate shocks we used the deviation from long-term rainfall patterns, capturing both drought and excessive rainfall.

Our findings suggest a strong relationship between rainfall anomalies and conflict intensity, which tends to be stronger in agro-ecological zones that are least resilient to climatic variability (such as Guinean savannah) and where (pre-)colonial political structures were less centralized. More importantly, we find evidence that the relationship is weaker in areas that specialize in the production of export crops (such as cocoa and palm oil) compared to subsistence farming areas, suggesting that agricultural diversification acts as an insurance mechanism against the whims of nature. Besides its several contributions, the findings of this study raised important questions pertaining (a) to the *key causal pathways* that drive the observed correlation and (b) to the *overall impact* of agricultural commercialization on rural incomes under colonialism. Questions that we sought to address in following chapters.

6.3 Did Commercialization Alleviate Social Distress?

In societies where large numbers of people live close to mere subsistence and rely heavily on rain-fed agriculture, recurrent episodes of climate extremes can be expected to prompt food scarcity and to fuel social tension and distress among their citizens. The extent to which smallholder farmers might adapt to climatic conditions, thereby *mitigating* the effect of climate on their livelihoods, remains largely debated (Brückner & Ciccone, 2011; Auffhammer et al., 2013; Klomp & Bulte, 2013; Burke et al., 2015). While a consensus has emerged in the literature on colonial legacies that tropical economies have expanded, to varying degrees, in response to access to colonial trade and agricultural commercialization, there is significant disagreement regarding the extent to which ordinary farmers have benefitted from such developments (Myint, 1958; Rodney, 1972; Bates, 1981; Fafchamps, 1992; Fieldhouse, 1999; Bates et al., 2007; Burgess & Donaldson, 2010; Iliffe, 2015).

In Chapter 3, we take up one aspect of this heated and long-lasting debate by exploring if and how cash crop cultivation made some districts more resilient in coping with climate shocks. Was agricultural commercialization beneficial or detrimental to rural livelihoods? Did access to external markets reduce or increase the uncertainty of a stable income? Did, then, relying on cash crops act as a *mitigation* mechanism to manage climate-shock exposure? Cash crops dominated the colonial economy, and except for some small mining and settler farming areas, most areas in our dataset experienced considerable smallholder-based agricultural commercialization (Cain & Hopkins, 1993). Therefore, the tropical economies under British rule provided us with a suitable context to study whether or not the cultivation of cash crops increased farmers' resilience against climate extremes.

Our findings suggest that commercialization of smallholder agriculture has had a *mitigating* effect on rural communities, as the surplus revenues generated by export crops partially alleviated negative rural income shocks, enabling farmers to diversify their capital portfolios, spread risks, smooth their consumption patterns, and profit from inter-regional and international trade. In this chapter, we sought to address empirical shortcomings and endogeneity issues. The main challenge in *causally* identifying the *mitigating effect* of cash crops on social distress arose from the fact that our interaction term (rainfall shocks × cash crop production) had to be exogenously determined rather than conditional on other local characteristics. Therefore, instead of merely proposing an endogenous mitigating effect which might overshadow other omitted explanations, we performed several additional (robustness) tests to refute alternative explanations. These robustness tests increase our confidence that the greater resilience to climate shocks observed in the cash crop regions was, in fact, due to the adoption of cash crops. Our findings, thus, lend support to the mechanism running from cash crop cultivation to greater resilience in the wake of climate shocks, as identified in the literature.

6.4 Poverty & Crime

Poverty has long been a question of great interest in a wide range of fields. Multiple scholarly disciplines –including economics, political science, history and anthropology, have observed and documented that poverty and crime go hand in hand. The literature distinguishes between absolute poverty (i.e. lack of the minimal material necessities for survival) and relative poverty (i.e. extreme income inequality). A great deal of previous research has demonstrated that absolute poverty is associated with higher property crime rates (Patterson, 1991; Miguel, 2005; Mehlum et al., 2006; Iyer & Topalova, 2014), while relative poverty has been linked to the surge of aggression and violent crime (Blau & Blau, 1982; Kelly, 2000; Fajnzylber et al., 2002).

While the theoretical foundations of poverty and crime have been well-established, the empirical basis for such an argumentation is considered speculative at best. One plausible explanation for this omission is the *endogenous* nature of the relationship between poverty and crime: deteriorating economic conditions may favor criminal activity, since more people are likely to engage in crime as an alternative source of income, while at the same time, higher levels of crime may undermine economic stability, investment and productivity. In other words, does poverty generate crime –or does crime lead to more poverty? Previous studies have been unable to resolve the key econometric identification issues and have been potentially subject to bias due to reverse causality and omitted variables, both of which distort simple ordinary least squares (OLS) estimates either downward or upward.

In Chapter 4, we use *exogenous* variation in rainfall as an instrumental variable for paddy-rice production to estimate the impact of poverty on different types of crime across British colonies in South and South East Asia (1910-1940). To achieve our objective, we pooled original data from a comparable set of districts within a similar ago-ecological setting, relying on the same staple crop (e.g. padi-rice) and sharing a rather uniform institutional framework (e.g. British colonial rule). Our key hypothesis was twofold: (a) if climate shocks lead to crime through subsistence crises, then these shocks should primarily affect the kinds of crime that alleviate loss of income, and (b) if climate-induced harvest failures are causing sharp increases in income inequality (relative poverty), for instance because some farmers or merchants benefit from exceptional market power during a period of food scarcity and food price hikes, we would expect more violent uprisings and grievances against people who were making money by exploiting the needs and misery of others.

Our findings suggest that climate-induced income shocks are a key underlying cause of property crime in British colonial Asia. A one-standard deviation decrease in annual food production increased property crimes by 21.1%

and vagrancy by 14.1%. While these effects are considerably higher in magnitude than the accumulated evidence from other studies reviewed by Hsiang et al. (2013), we argue that this may be explained, to a considerable extent, by the fact that we are dealing with a highly agrarian/non-industrial part of the world, where, at the time, the vast majority of the total income derived from agricultural practices and urban labor was relatively limited. As to our second hypothesis, no effect was found between food production and violent crime, something that serves as an important validation of our empirical strategy, and highlights the importance of looking beyond aggregate crime measures in the climate-economy literature, since they may obscure heterogeneous patterns across crime categories.

Beyond improving our understanding of local conditions of early twentieth century South and South-East Asian states, the implication of this study may be important from a public policy perspective in contemporary developing countries. While this chapter's aim is to apply this approach to economic history, it may also be extended to more present-day developing countries. Taken together, the results of this research support the idea of improved high-yield climate-resistant grains and investments in irrigation technology. The promise of a stable annual harvest would potentially eliminate much of the adverse crime-induced poverty traps, as well as the subsequent unfolding vicious cycle of crime.

6.5 Did African Farmers Face Greater Climatological Insecurity?

Adverse climatological conditions have been a frequently cited cause for disappointing productivity growth in *African* agriculture, and a key factor in explaining low population densities and persistent levels of poverty. So far, little attention has been given to the fact that rainfall patterns in tropical Africa may exhibit a greater degree of year-to-year variability than in other tropical areas. While under relatively predictable rainfall patterns, farmers adapt their production practices to maximize their yields, whereas under high levels of *rainfall variability* (where more frequent and intense shocks occur) such adaptation becomes more difficult. Contrary to studies using contemporary climate data (Bloom et al., 1998; Gallup et al., 1999; Le Blanc & Perez, 2008), we use data from an era *before* the demographic explosion of the second half of the twentieth century to address two questions of historical significance: has rainfall, on the whole, been more insecure and thus less predictable in tropical Africa than in tropical Asia? And if so, can this insecurity partly explain the difference in population densities?

In Chapter 5, we explore a newly constructed dataset of annual and monthly rainfall returns for 221 districts in tropical Africa (141) and Asia (80) between 1920 and 1940. We refine existing measures of rainfall variability by parameterizing rainfall in three distinct measures: (a) the overall variation in annual rainfall using the *coefficient of variation* (CV), (b) the *frequency* of rainfall shocks (defined as the number of annual mean deviations exceeding one standard deviation) and the *intensity* of rainfall shocks (the average magnitude of the deviation). Our results were two-fold. First, we find that rainfall patterns and shocks, on the whole, were more erratic in tropical Africa than in tropical Asia, and second, that, controlling for mean rainfall levels, rainfall *variability* explains a considerable part of the variation in population densities across tropical Africa and Asia. Taken together, such results add supporting evidence to the idea that climatological instability breeds higher cultivation risks and causes worse prospects for investments in agricultural technologies, which, as a result, have impeded long-term agricultural intensification in tropical Africa.

6.4 Future Research Avenues

While this emerging body of literature is providing many new insights into the climate-economy nexus, it has also generated ample room for further progress and investigations in numerous directions. The *first direction* that remains to be elucidated is research into the key causal pathways linking climate to the societal outcomes of interest. It seems very likely that climate extremes influence societies through multiple pathways that may vary between contexts. For instance, while there is, to some extent, a consensus that economic factors are important pathways in relatively poor countries, the strong evidence that temperature extremes (e.g. heat waves) increase crime rates in wealthier societies as well (see for example Ranson, 2014), suggests that other extra-economic factors (e.g. psychological) may be at play. While tentative, in Chapter 4 we were able to confirm such a direct (extra-economic) effect between high temperature and violent crime.

A *second direction* for future work would be to better understand the heterogeneous effects of climate on society, as heterogeneity largely depends on the applied context (both within and between contexts). If we compare the findings we obtained in the African context (Chapters 2 & 3) with that of the Asian economies (Chapter 4), it appears that, in an African context, distress and conflict were more acute in years with excessive rainfall than in years with droughts. In the rice economies of Asia, however, this effect appears in reverse (relatively more crime is experienced in drought years than in flood years). In either case, identifying heterogeneity in a wide variety of contexts (both historical and contemporary) is a research objective that holds great promise, as it is central to designing *tailor-made* policies and institutions that best respond to imminent climate extremes.

Overall, the findings of this study have gone some way towards enhancing our understanding of the heterogeneous effects of climate on historical societies. The principal implication of such findings is that agricultural diversification and openness to interregional and international trade acted as an insurance mechanism to African smallholders against the whims of nature. Our results are interesting also from a public policy perspective, as they support the idea that smallholder-based export cultivation (i.e. switching from subsistence or semi-subsistence farming to cash cropping) might lead to higher production yields per hectare, greater financial profits and more sustainable livelihoods for farmers. That *even in a colonial context*, smallholder-based export crop cultivation had a mitigating effect on weather-induced distress, suggests that providing smallholders with the ability to produce for external markets should be a key policy priority. At the same time it would be unwarranted, even reckless, to claim that 'state sponsored' export crops are a 'magic bullet', or even that agricultural commercialization in general is universally beneficial to mitigating rural societies' vulnerability to weather shocks. When interpreting our findings, it is particularly important to consider the fact that most of colonial tropical Africa was *land abundant*, that smallholders combined cultivation of export and subsistence crops, and that while inputs were low and farming techniques basic, smallholders generally did not have to incur debts to participate in cultivation for export.

Yet, important research questions still remain open. For example, while this study finds a *short-term* mitigating effect of agricultural commercialization, it does not address the *long-term* (positive or negative) consequences that have been proposed in the literature; for instance, the long-run underdevelopment of African living standards, the disruption of traditional insurance mechanisms or the environmental impact of agricultural commercialization. We expect that a natural progression of this work would be to investigate the *long-run effects* and *legacies* of cash crops.

A *third direction* would be to use the vastly important, but largely unexploited, African and Asian colonial archives to construct *temporally* and *spatially* consistent and *internationally* comparable climatological series for a wide range of indicators (such as precipitation, temperature, wind speed etc.) and to connect these to existing datasets. To date, we hardly possess any evidence on *observed* (i.e. from meteorological stations) monthly and annual climate data prior to 1960. To overcome such data gaps, researchers have developed a number of *forecasted* weather data sets, using either interpolations across space and time, or data assimilation algorithms. While these procedures offer free and easily imported climate datasets in formats that can be used by many researchers (e.g. gridded data), they also increase the statistical uncertainty of resulting parameter estimates (Hsiang, 2016). Additionally, there are also drawbacks from an econometric point of view. These data-generating processes often display significant spatial correlation and increased risk of measurement error. Such statistical concerns may lead to inflated standard errors on the employed weather variables and to biased estimated coefficients (Wooldridge, 2010; Auffhammer et al., 2013).

A *fourth direction* would be the bridging of the well-identified *short-run* climatic fluctuations to *medium* and/or *longer-run* outcomes. Recent empirical and computational advances have enabled researchers to use panel techniques to credibly provide evidence on the impact of short-run climate fluctuations on long-run outcomes (see for example Dell et al., 2012). A good example of such an approach was Chapter 5, where we show that *short-run* rainfall shocks had adverse *long-run* consequences by impeding long-run agricultural intensification.

6.5 Final Remarks

The impact of climate on economic development and social activity in general, is a topic of considerable urgency today as the process of global climate change accelerates, generating more severe and unpredictable weather events, as well as more erratic rainfall patterns. While human societies have historically adapted, at least to some degree, to a certain range of climatic variability, climate change and its associated consequences are unprecedented in intensity and rapidity, affecting virtually all aspects of daily life –including the availability of water resources, the quality of water supplies, where and how food is grown, and heat and cold-related deaths, to name a few. While much work remains to be done in developing a road map of adaptation to global warming, carefully understanding the key *causal pathways* would be a vital step in developing strategies for potential interventions. The more we grow to understand the underlying mechanisms, the better we can design relevant policy responses and adaptive institutions.

The success of such efforts will be progressively important in the coming decades, as changes in climatic conditions will amplify the risk of food insecurity, disease and conflict. Unfortunately, climate change continues and will bring about more erratic weather events, hitting the poorest small-scale farmers the most. A key policy priority should therefore be to aim at a long-term protection of the most vulnerable and precarious farmers of the global south, helping them maintain and increase their crop productivity (whether the policy target is to develop new technical innovations such as heat and drought-resistant traits that can boost crop's tolerance; or to introduce new agricultural implements such as high-yielding varieties in association with irrigation schemes to compensate for ever shorter rainy seasons). In either case, building resilience among small-scale farmers is not just about protecting their incomes and alleviating human misery, it is also about maintaining global food security.

References

Auffhammer, M., Hsiang, S. M., Schlenker, W., & Sobel, A. (2013). Using weather data and climate model output in economic analyses of climate change. *Review of Environmental Economics and Policy*, 7(2), 181-198.

Bates, R. H. (1981). *Markets and States in Tropical Africa: The Political Basis of Agricultural Policies*: University of California Press.

Bates, R. H., Coatsworth, J. H., & Williamson, J. G. (2007). Lost Decades: Post-independence Performance in Latin America and Africa. *The Journal of Economic History* 67, 917-943.

Blattman, C., & Miguel, E. (2010). Civil war. *Journal of Economic literature*,*48*(1), 3-57.

Blau, J. R., & Blau, P. M. (1982). The cost of inequality: Metropolitan structure and violent crime. *American Sociological Review*, 114-129.

Brückner, M., & Ciccone, A. (2011). Rain and the democratic window of opportunity. *Econometrica*, *79*(3), 923-947.

Burgess, R., & Donaldson, D. (2010). 'Can openness mitigate the effects of weather shocks? Evidence from India's famine era'. *The American economic review*: 449-453.

Cain, P. J., & Hopkins, A. G. (1993). *British Imperialism: Crisis and Deconstruction, 1914-1990* (Vol. 2). Addison-Wesley Longman Limited.

Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, *4*(3), 66-95.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature*, 52(3), 740-798.

Fafchamps, M. (1992). Cash Crop Production, Food Price Volatility, and Rural Market Integration in the Third World. *American Journal of Agricultural Economics*, 74(1), 90-99.

Fajnzylber, P., Lederman, D., & Loayza, N. (2002). What causes violent crime?. *European Economic Review*, *46*(7), 1323-1357.

Frankema, E. (2014). Africa and the Green Revolution A Global Historical Perspective. *NJAS-Wageningen Journal of Life Sciences*, 70, 17-24.

Fieldhouse, D. K. (1999). *The West and the Third World: trade, colonialism, dependence, and development:* Blackwell Oxford.

Hsiang, S. M., Burke, M., & Miguel, E. (2013). 'Quantifying the influence of climate on human conflict'. *Science*, 341(6151): 53-67.

Hsiang, S. M. (2016). Climate Econometrics (No. w22181). National Bureau of Economic Research.

Iliffe, J. (2015). *Emergence of African Capitalism*. Springer.

Iyer, L., & Topalova, P. B. (2014). Poverty and crime: evidence from rainfall and trade shocks in India. *Harvard Business School BGIE Unit Working Paper*, (14-067).

Kelly, M. (2000). Inequality and crime. *Review of economics and Statistics*,*82*(4), 530-539.

Klomp, J., & Bulte, E. (2013). Climate change, weather shocks, and violent conflict: a critical look at the evidence. *Agricultural Economics*, *44*(s1), 63-78.

Miguel, E. (2005). Poverty and witch killing. *The Review of Economic Studies*,*72*(4), 1153-1172.

Myint, H. (1958). The classical theory of international trade and the underdeveloped countries. *Economic Journal, 68*, 317-337.

Papaioannou, K. J. & Van Zanden, J. L.,(2015). The Dictator Effect: How Long Years in Office Affect Economic Development. *Journal of Institutional Economics*, 11 (1), pp.33-47.

Patterson, E. B. (1991). Poverty, income inequality, and community crime rates. *Criminology*, *29*(4), 755-776.

Ranson, M. (2014). Crime, weather, and climate change. *Journal of environmental economics and management*, *67*(3), 274-302.

Rodney, W. (1978). *How Europe Underdeveloped Africa*: Bogle-L'Ouverture Publications, Howard University Press.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.

Summary (English)

The idea that climate may substantially influence human behaviour and economic performance is a very old one. In recent years, there has been a rapidly growing body of literature across multiple scholarly disciplines aiming to quantify and assess the net effect of climate on a number of socially and economically relevant outcomes. Building entirely on original primary sources, this dissertation provides some of the first evidence in a *colonial setting* on the causal effects of climatic conditions on crime, conflict and patterns of human settlement. It provides evidence from British colonial Africa and Asia during the first half of the twentieth century. The research strategy consists of both a qualitative and an econometric component. By merging the theoretical and empirical insights of several strands of literature –including economic history, geography and the new climate-economy literature, it aims to simultaneously address both an *academic challenge* (i.e. disentangle the net effect of climate on society from the many other contextual factors) and a *social question* of prime importance (i.e. reveal key mitigating factors that would facilitate targeted and effective policy interventions in rural communities).

In Chapter 2, we begin by demonstrating the effects of climate shocks on inter-communal conflict in colonial Nigeria (1912-1945). This investigation takes the form of a historical micro-level case-study, using primary historical sources on court cases, prisoners and homicides to capture conflict. Our findings suggest a strong relationship between rainfall deviation and conflict intensity. This relationship tends to be stronger in agro-ecological zones that are least resilient to climatic variability (such as Guinean savannah) and where (pre-) colonial political structures were less centralized. More importantly, evidence is found that this relationship is weaker in areas specializing in the production of export crops compared to subsistence farming.

In Chapter 3, we review a heated and long-lasting debate in African economic history, by exploring if and how cash crop cultivation resulted in some districts becoming more resilient to exogenous shocks. Was agricultural commercialization beneficial or detrimental to rural livelihoods? Did access to

external markets reduce or increase the uncertainty of a stable income? Did, then, relying on cash crops act as a *mitigation* mechanism to manage climate-shock exposure? Our findings suggest that commercialization of smallholder agriculture did have a *mitigating* effect on rural communities, as the surplus revenues generated by export crops partially alleviated negative rural income shocks enabling farmers to spread risk, smooth their consumption patterns, and profit from inter-regional and international trade.

In Chapter 4, we use *exogenous* variation in rainfall as an instrumental variable for padi-rice production in order to estimate the impact of poverty on different types of crime across British colonies in South and South East Asia (1910-1940). Our findings strongly suggest that climate-induced income shocks were a key underlying cause of property crime in British colonial Asia. A one standard deviation decrease in annual food production increased property crimes by 21.1% and vagrancy by 14.1%.

Chapter 5, explores two research questions. Have rainfall regimes been more insecure and thus less predictable in tropical Africa than in tropical Asia? And if so, can this explain part of the difference in human settlement patterns? Our results suggest, first, that rainfall patterns and shocks were indeed more erratic in tropical Africa than in tropical Asia, and second, that rainfall *variability* explains a considerable part of the variation in population densities across tropical Africa and Asia. These results add sound supporting evidence to the view that climatological instability breeds higher cultivation risks and worse prospects for investments in agricultural technologies, which, as a result, have impeded long-term agricultural intensification in tropical Africa.

Finally, Chapter 6, reviews the main lessons learned within each preceding chapter, discussing the resulting policy recommendations, and the implications for future research. Overall, it is our ambition that this study's insights into the negative relationship between climate extremes on food crises and conflict within vulnerable rural societies, should prove particularly valuable to both academics and policy makers alike.

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Of all the things which wisdom provides to make us entirely happy,
much the greatest is the possession of friendship.

–Epicurus

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Publications

Papaioannou, K. J., (2017). "Hunger Makes a Thief of Any Man: Poverty and Crime in British Colonial Asia" *European Review of Economic History*, *21*(1), pp. 1-28.

Papaioannou, K. J. & De Haas M., (2017). "Weather Shocks and Agricultural Commercialization in colonial Tropical Africa. Did Cash Crops Alleviate Social Distress?" *World Development*, *94*(1), pp. 346–365.

Voors, M., Van Der Windt, P., Papaioannou, K. J., & Bulte, E. (2017). Resources and governance in Sierra Leone's civil war. *The Journal of Development Studies*, *53*(2), pp. 278-294.

Papaioannou, K. J. (2016). "Climate Shocks and Conflict: Evidence from Colonial Nigeria" *Political Geography*, *50*(1), pp. 33-47.

Papaioannou, K. J. & Van Zanden, J. L.,(2015). "The Dictator Effect: How Long Years in Office Affect Economic Development" *Journal of Institutional Economics*, *11*(1), pp. 111-139.

Papaioannou, K. J. & Dalrymple-Smith, A. (2015), "Political instability and discontinuity in Nigeria: The pre-colonial past and public goods provision under colonial and post-colonial political orders", *The Economics of Peace and Security*, *10*(1), pp. 40-52.

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Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the activity	Departure/Institute	Year	ECTS*
A) Project related competences			
Seminar: My project in a nutshell	N.W. Posthumus Institute	2013	2
Seminar: Work in progress	N.W. Posthumus Institute	2013	6
Research Design course	N.W. Posthumus Institute	2014	8
Individual Assessment	N.W. Posthumus Institute	2014	1
Masterclass	N.W. Posthumus Institute	2015	2
Ester Advanced seminar	N.W. Posthumus Institute	2015	4
PhD Conference	N.W. Posthumus Institute	2015	2
B) General research related competences			
Introduction Course	WASS	2013	1
Research Proposal	WASS	2013	4
'Climate Shocks and Conflict in Colonial British Africa: Did Export Crops Mitigate the Impact of Weather Shocks?'	40th Social Science History Association Conference, Baltimore, USA	2015	1
Panel Organizer 'Societal Responses to Exogenous Shocks: Vulnerability and Resistance in Pre-Industrial Europe and Africa'	40th Social Science History Association Conference, Baltimore, USA	2015	2
'Weather shocks, social upheaval and cash crops: Evidence from colonial tropical Africa' (best paper by PhD award won)	11th Social Science History Conference, Valencia, Spain	2016	1
C) Career related competences/personal development			
Academic Writing Course	WGS	2014	2
GIS Introduction Course	GeoDesk, WUR	2014	2
Visiting scholar UC Berkeley	UC Berkeley, USA	2015	6
Extensive Archival Research	London, UK	2013-2015	3
TOTAL			**47**

* one ECTS credit is on average equivalent to 28 hours of study load.

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